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CEMENT IN SEAWATER

PRESENTED
TO THE MEMBERS OF THE INTERNATIONAL ASSOCIATION
FOR TESTING MATERIALS

BY

SCANDINAVIAN PO[illegible]T MANUFACTURERS

SPON & CHAMBERLAIN
BOOKS ON
Mechanics, Engineering,
Electricity, Trades, &c
123 Liberty Street, N. Y.

THE INTERNATIONAL ASSOCIATION
FOR TESTING MATERIALS 5TH CONGRES COPENHAGEN,
SEPTEMBER 1909.

CEMENT IN SEAWATER

REPORT ON THE TRIALS, COMMENCED IN
1896 ON THE RECOMMENDATION OF THE

SOCIETY OF SCANDINAVIAN PORTLAND CEMENT MANUFACTURERS

BY

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COPENHAGEN
PRINTED BY J. JØRGENSEN & CO. (M. A. HANNOVER)
1909

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1. Planning of the experiments.

At a meeting of the Scandinavian Portland Cement Manufactures in April 1896, it was decided to appoint a committee to investigate the influence of sea water on Portland cement.

A preliminary programme was drawn up as a basis for the committee to work upon, and it was also agreed that the committee should apply to the Norwegian Harbour Board and to the »Office of Harbours and coast protection« in Denmark for assistance in the work (see Appendix 1, Report of the meeting).

The following gentlemen were elected as members of the committee:

K. Buch, Esq., Chief Chemist, Aalborg Portland Cement Works, Aalborg.

I. W. Luudh, Esq., Chief Chemist, Hellekis Portland Cement Works, Hellekis.

Dr. *Morris-Haslinger*, Chief Chemist, Christiania Portland Cement Works, Slemmestad.

A. Poulsen, Esq., Resident engineer to the office of harbours and coast protection, Lemvig.

B. H. Wallin, Esq., Chief Chemist, to the »Chalmer Institute«, Gothenburg.

In 1899 *O. Kjellström*, Esq., director of »Skånska Cementgjuteri A.B.«, Stockholm, joined the committee.

The first meeting of the Salt-water Committee was held in Copenhagen 13. June 1896; all five members were present, and *A. Poulsen* was elected chairman.

At the meeting the programme for the working of the committee was drawn up. It was agreed to arrange comparative mortar tests with different brands of Scandinavian Portland cement and to include one class of cement from each of the three countries and in addition to try an English Portland cement and also the hydraulic lime — »Chaux du Teil« — which is highly valued in the

French Mediterranean districts. It was considered unnecessary to include any of the German cements on account of the great similiarity in the methods of manufacture in Germany and Scandinavia.

The trials were to be made partly with mortar cubes (for crushing tests) and partly with concrete blocks; in the beginning, with a total quantity of about 3500 cubes and about 10 cubic meter of concrete (Appendix 2, working plans).

It was agreed, however, later (1897) to extend the concrete trials, by moulding concrete blocks of several other kinds of cement, or cement admixtures and with different hydraulic mortars, together with sands of different fineness. These trials have, in the course of the last few years, brought the total of concrete samples up to about 70 cubic meter.

2. Plans for mortar tests.

The following five kinds of cement were chosen for the experiments:

Danish Portland cement, Aalborg Portland-Cement Fabrik, Aalborg.
Norwegian Portland cement, Christiania Portland Cementfabrik, Christiania (Slemmestad).
Swedish Portland cement, Skanska Cement A.B., Lomma-Limhamn.
English Portland cement, Nine Elms Cement Works, London.
French hydraulic lime, Chaux du Teil.

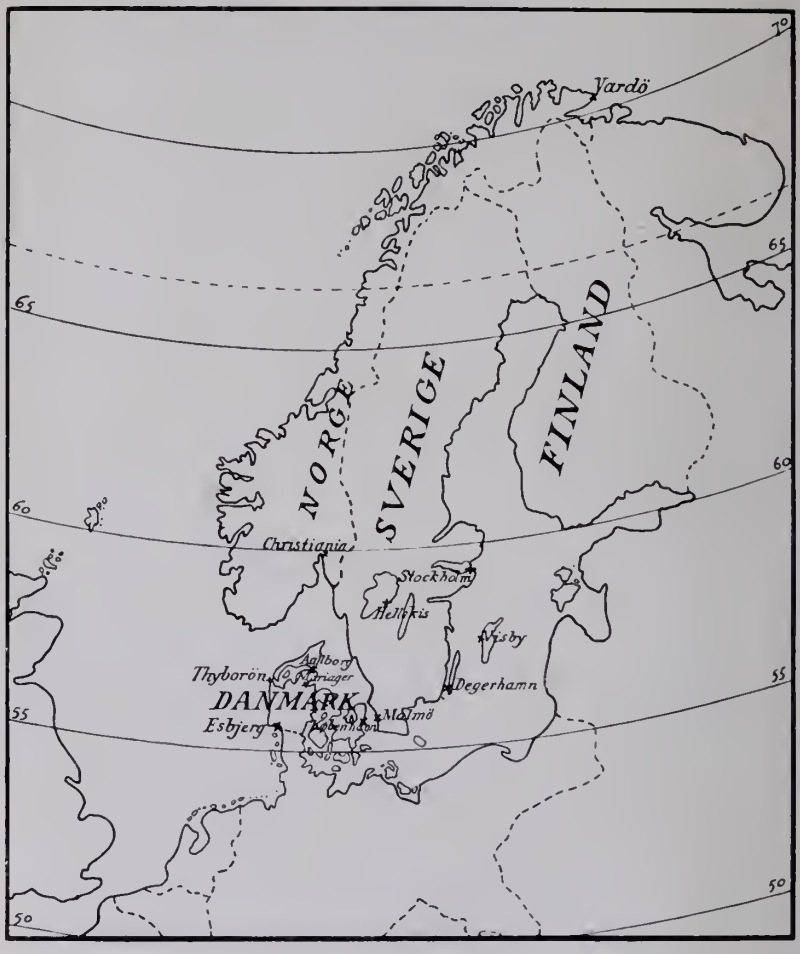
Bornholm normal sand was used for the mortar although an additional series of samples was moulded (of Aalborg cement) — with west Jutland coast sand from Thyboron — forming in the whole six test series after the substance of the mortar.

In each of these mortar series were four test cubes moulded of the normal size (= 50 cm² in cross section or a little over 7 cm on the side line) with following ratios of mixture:

4 cubes containing 1 part cement to 3 sand
4 » » 1 » » - 2 »
4 » » 1 » » - 1 »
and 1 » » 1 » » - 0 » (neat cement)

Appendix 4.

Map of Scandinavia.



Cement Works.

Denmark. Near Aalborg: 1 Aalborg, 2 Danmark, 3 Norden, 4 Nørresundby. — Near Mariager: 5 Cimbria, 6 Dania, 7 Kongsdal.

Sweden. 8 Hellekis, 9 Degerhamn, 10 Visby. — Near Malmö: 11 Lomma-Limhamn, 12 Klagshamn.

Norway. 13 Christiania.

altogether 13 test cubes for each of the five series with normal sand, and 12 cubes for the series with coast sand. These 77 test cubes making in all one set.

The »Chaux du Teil« required was kindly sent by Mons. *Guérard,* Engineer in charge at Marseilles harbour, who, being interested in the matter, took care that the quality received was the same which he had recommended for the tests (viz: sifted lime from the firm *I. & A. Pavin de Lafarge*, Departement of Ardèche) and supplied the necessary information as to the correct proportions, in which the »Chaux du Teil« should be mixed with sand (Appendix 3. Mons. *Guérards* letter of $^{11}/_{7}$ 1896).

The test cubes were marked with a number written with pencil and, in addition, beads were moulded in the mass and distributed over the surfaces, so that the different colours and sizes of the beads could be used as a distinguishing mark for the different admixtures and kinds of cement.

These test cubes were — according to the plans — to be kept for one month after moulding in moist air to harden and then to be placed in sea water under conditions as much as possible resembling those under which cement is used for coast and harbour work at the sea. As places for the trials, Esbjerg harbour was chosen as the southernmost point of the coast of Denmark on the North Sea, and Vardo harbour in Norway as the extreme opposite (Appendix 4: map of Scandinavia). At both places experience has been gained on the detrimental effects of sea water on concrete, undoubtedly in connection with the effect of frost. It was agreed therefore, that, at both places, two sets of test samples should be placed: — one at a point between high and low water, so that under the daily ebb and flow it would, at high water, be saturated twice every 24 hours, and similarly at low water be dried by the air or exposed to the frost. Another set of test samples was placed so far below the lowest water mark, that they were always protected against the frost.

To these four test places, — at Esbjerg and Vardo, — a fifth was added at Degerhamn harbour on the Baltic, where the amount of salt contained in the water is so small, that it can be taken as practically uninjurious to cement. It was decided to arrange the test samples at this last named place so as to keep them free from frost by placing them under the lowest known water level.

The local conditions at the test places will be more fully described later (see paragraph 4).

From each of the five test places a set of test cubes (77 pieces) should be taken up and sent back for crushing tests at intervals of ¼, ½, 1, 2, 4, 6, 10, 15 and 20 years; that is 9 different periods from the date of moulding. There were accordingly required $77 \times 5 \times 9 = 3465$ test cubes, and of these — at the present moment — the 15 and 20 years cubes are still in the sea, so that this paper only reports on the tests of up to 10 years duration.

It was agreed to analyse the test cubes after crushing and eventually to take photographs of such cubes or fractures, which presented the most typical aspects.

The purpose of these analyses was to show what chemical alterations had taken place and in what manner these had penetrated from the surface. A scheme for these investigations was drawn up by a sub-committee, elected from the committee and consisting of *K. Buch*, Esq., *I. W. Lundh*, Esq., and Dr. *Morris-Hasslinger;* — *I. W. Lundh*, Esq., was elected chairman (Appendix 5, Analyses scheme).

3. Plans for the trials with concrete blocks.

The trials with the concrete blocks could not, of course, be carried out in as rational a manner as with the mortar cubes, as crushing tests of the pieces could not take place, and the analysis of the pieces of concrete could be expected to vary considerably with the different admixtures of ballast or crushed stone, so that all exactness would only be illusory. Under these circumstances it is necessary to rely only on the close observation of the trial blocks.

The place where such a trial could take place was that portion of the west coast of Jutland, where the state was engaged with coast protection work; the place best suited for the trials was found to be »groin 59« at Thyboron canal, on account of it being only necessary to use blocks of about 0,6 cubic meter here, whereas at the other groins, blocks of about 1,7 cubic meter were being used.

Even here with the dimensions of 0,6 cubic meter (weighing about 1400 kg) it was necessary to mould the blocks of the local

ballast and sand, which, however, was well adapted for concrete work. A very important point was to get the mixtures as uniform as possible with the different kinds of cements, and above all not to get too small a proportion of cement to make the concrete weak, whether the cement were good or bad.

The shingle ballast and sand available have, under the influence of the waves, been worn round, but with fresh and chemically clean surfaces and absolutely free from admixture of clay or other impurities. Out of 100 pebbles, over 90 pCt. were flint, and the sand was almost pure quartz. For the concrete blocks, to be placed in the groins, was used ballast with from 10 to 150 pebbles per kg. in mixtures of larger and smaller stones.

The water-carrying capacity of sand and ballast is about 34 pCt. and 38 pCt. respectively, and it should theoretically be possible to get a close mixture by using one cubic meter of cement to about 3 cubic meter of sand and about 9 cubic meter of pebbles. In breakwater work, however, it has lately been practice to use a mixture of $1 + 2\frac{1}{2} + 5\frac{1}{2}$, in other words, 540 kg. cement per cubic meter sand, with a fair surplus of mortar in the concrete. For the test blocks it was agreed to use the following mixtures: $1 + 1 + 2\frac{7}{8}$, $1 + 2 + 4$ and $1 + 3 + 5\frac{1}{8}$ of which the first and the last were proportioned such, that the surplus in them was the same as for the mixture $1 + 2 + 4$.

Of these three mixtures blocks should be moulded of each of five kinds of cement chosen for the mortar cubes; viz four Portland cements: 1) Aalborg, 2) Christiania, 3) Lomma-Limhamn, 4) Nine-Elms and a fifth »Chaux du Teil«, — and the blocks should be used as integrating parts of groin No. 59. But as several other cement manufacturers, and other interested parties, wished to have their materials tested under the same conditions, permission hereto was granted, so that in the course of time the following Portland cements were represented: 6) Hellekis, 7) Dania, 8) Cimbria, 9) Danmark, 10) Hemmoor, 11) Norden and 12) »quick-setting Aalborg«; together with the following special mouldings:

1) Tras + cement, 2) infusoriat earth (Mo-Ler) + cement, 3) Lomma with admixture, 4) Slag-cement, 5) Dania with admixture, 6) sandcement, 7) »Kinnipple« concrete, 8) Hollow re-inforced blocks, 9) Santorin + cement, 10) ditto + lime, 11) Puzzolan + cement, and 12) ditto + lime.

It is expected that several others will — in the course of time — be added to the above list, especially as new cement works are continually being erected.

Besides the blocks moulded with the ordinary — quite fine — strand sand from Thyborøn, blocks were moulded with sand of different degrees of fineness, but with uniform pebbles and cement. For this was chosen Aalborg cement, which had already been chosen for the above mentioned mortar cubes partly with normal sand and partly with strand sand.

The coarser moulding-sand, which is often sorted by the sea and piled up on the beach, was classified into three sizes: coarse, medium and fine, and afterwards mixed in different proportions. A review of these proportions will be found in appendix 6, where the water-carrying capacity of the sand is shown by curves; the different mixtures chosen for these test samples are numbered as follows:

1	coarse (C)	7	$^1/_3$ C + $^1/_3$ M + $^1/_3$ F.
2	medium (M)	8	$^1/_6$ C + $^1/_6$ M + $^2/_3$ F.
3	fine (F)	9	$^1/_6$ C + $^2/_3$ M + $^1/_6$ F.
4	½ C + ½ M	10	$^2/_3$ C + $^1/_6$ M + $^1/_5$ F.
5	½ C + ½ F	11	$^2/_3$ C + 0 M + $^1/_3$ F.
6	½ M + ½ F	12	0 C + $^2/_3$ M + $^1/_3$ F.

The two last named proportions were added because — especially with No. 11 which only contains 24 pCt. intervals — it could be expected that a very close and therefore insusceptible concrete would result; of each of the sand mixtures two blocks were moulded with the proportions, 1 cement + 2 sand + 4 pebbles and 1 + 3 + $5^1/_8$, while the composition 1 + 1 + $2^7/_8$ (used for the other mouldings) was not used here as it was considered to be without practical interest.

On the other hand, however, a fourth proportion was occasionally included, viz: 1 + 2½ + 5½ because this is the one which is used for the ordinary concreting work on the groins: — and of some of the sample blocks two mouldings were made. The total number of blocks has in his manner reached over one hundred.

On some of the blocks one half of the upper surface was trowelled and a galvanised-iron number-plate with full inscription was fastened on to these blocks. In order to be able to lift or

Appendix 6.

Concrete tests with sand of different fineness.

The sand used was West Jutland coast sand (from Thyborön) which was separated into three degrees of fineness by sifting, viz:

I. coarse.

Passes through sieve with about 4 mm. mesh
Kept back by » » » $1^1/_2$ » »

II. medium.

Passes through sieve with about $1^1/_2$ mm. mesh
Kept back by » » » 120 meshes pr. cm².

III. fine.

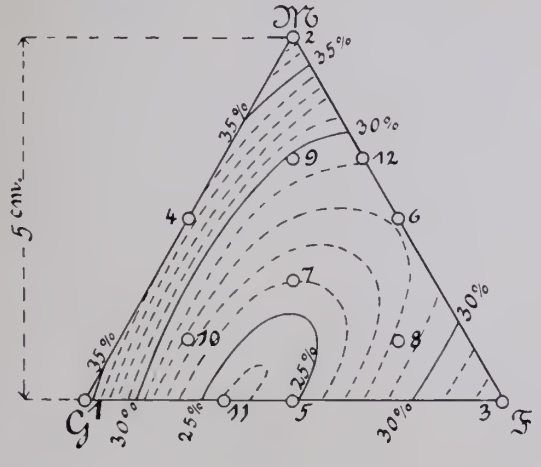
Passes through sieve with about 120 meshes pr. cm², but rinsed from all dust-particles by the natural washing ot the sea.

On the figure below, for every point, the contents of fine (F.), coarse (G.) or medium (M.) sand is shown by the distance of the points from the side of the triangle, respectively G. M., F. G. and F. M., which distance shows the percentage, when the »height« of the triangle (which is about 5 cm) is taken to equal 100.

The curves in the figure show the percentage of spaces in one cubic measure of that sand admixture, which the individual point represents, according to the above.

The sand admixtures of which the blocks were moulded will be found marked by a circle. Twelve blocks were moulded of ballast 1 : 2 : 4 and twelve of 1 : 3 : $3^1/_2$, all containing about 0,6 cubic meter concrete.

Aalborg cement was used for these tests.



remove the blocks by crane, a galvanised bolt was built into the block with nut and washer imbedded in the concrete, and with the bolt head protruding a little over the upper surface. On the bolts, as well as on the washers in the concrete, were arranged identifying marks and finally beads were mixed in the mortar so as to indicate the proportion between the cement and sand. Furthermore with the pebbles were mixed larger pieces of broken, coloured glass to designate the kind of cement. It will thus be seen that quite a small portion of one of the blocks can as a rule be identified.

4. Local conditions on the test places.

Great care was taken, both for the mortar cubes and for the concrete blocks, that they should be exposed to the natural conditions prevalent in coast protection or harbour work. As far as the concrete blocks are concerned it can easily be seen that this could best be done by placing them in a groin near Thyboron canal, whereas for the mortar cubes, — which could not be placed on the open sea coast, — the most promising conditions would be found in Esbjerg and Vardo harbours.

From all three places definite information on the deterioration of concrete has already been collected. It was for this reason that the »State office of harbours« in Norway and the »office of harbours and coast protection« in Denmark showed great interest in the matter when applied to for assistance, and through them the help of the local engineers was obtained. These engineers undertook the advising as to proper places for the tests and also gave their assistance in arranging the details of the placing of the blocks and the removal again at the proper times. For this work great credit is due to Mess[rs] *H. B. Olsen* and *Joh. Eide* engineers at Vardo harbour; and at Esbjerg harbour to the director of harbours and coast protection, Mr. *V. Vestergaard* formerly engineer in charge of Esbjerg harbour and to Mr. *L. v. Barner*. At Thyboron the work has been carried out under the direction of the chairman of the committee in his capacity of engineer to the »office of harbours and coast protection«.

At Degerhamn harbour — the place chosen for depositing the blocks in the Baltic sea — the matter was carried out by one of

the members of the Society of Portland cement manufacturers, »Ölands nya Cement A. B.«.

At Esbjerg harbour, the work on which was commenced in 1868, concrete was used as the principal material, as the dock bassin, its quays and lock is built entirely of concrete. Furthermore in 1875—78 a mole of about 1000 m. length was built for conducting the current in the right direction in front of the dock gate. All the moulding was as far as possible carried out in dry trenches. As far as the mole is concerned, the work was executed during low water with interruptions at high tide, as the largest part of the mole only reaches up to high water mark.

The daily tide at Esbjerg is about 1½ m.; the climate here, at Denmarks south- westerly corner, is comparatively mild in winter on account of the regulating influence of the North Sea, although during longer periods of east wind the temperature can — as everywhere in Denmark — drop to 10—20° C. degrees of frost, so that the concrete (especially in the mole) has been exposed to daily freezing during low water in winter, or to the drying of the salt water in the summer. The harbour is, however, well protected against the action of the waves, by the Island of Fanø. The mean temperature of the air is about 7½ degrees centigrade, the temperature of the water perhaps a fraction of a degree less.

After the lapse of a few years the concrete in the mole was seen to be greatly affected, and it was supposed that the frost and the ice drift at high tide were the chief causes. A great portion had already been rebuilt, before ten years had gone, by covering the back of the mole with granite in cement mortar. This, however, was also destroyed, so that in 1888 all the parts above low water were again rebuilt with large hewn blocks of granite laid, without mortar of any kind, on a bed of smaller stones, in place of concrete.

On the other hand the quays and lock of the dock bassin have stood comparatively well; they have however later been rebuilt, not because they were damaged to any great extent but on account of the arising necessity of a greater depth of water in the bassin.

The concrete work in the mole has hardly been of poorer quality than in the dock, and the destruction can safely be placed to the effect of the tide together with frost and ice drift. The cement used at the commencement was English *(Johnson)*, later

German (*Alsen, Palhude* and *Hemmoor*) and the mixing of the concrete appears to have been quite normal; fine sand and crushed granite was used. That sea water was partly used for the mixing can hardly be considered destructive.

The protection of the coast at Thyboron was commenced in 1875, and there has yearly been moulded up to fifty thousand cubic meter of concrete, for the greatest part in blocks of $1^2/_3$ cubic meter, which have been allowed to remain for a month or more on the beach before being placed in the groins. At the commencement the mixture was 1 portion of cement, 3 sand and 6 — newly washed up — shingle ballast, but from 1884 the poor mixture of 1—4—8 was introduced. After the lapse of from six to eight years, it was found that these blocks were crumbling to a great extent. As the result of this, the proportion from 1894 was put up to 1 : 2 : 4, but in 1901 again lowered a little to 1 : $2^1/_2$: $5^1/_2$. (2 : 5 : 11), which must be considered a rich mixture as — according to the measurements of the crevices to be filled in the material — the proportion of about 1 : 3 : $7^3/_4$ would — theoretically speaking — give a completely close concrete. Since 1902 the concrete has been mixed on machine (Gante and Gockel) and moderatly fresh water has been used.

Several different kinds of cement have been used for the groins, at the commencement German, later Danish, as the different Danish works were built viz: Cimbria, Dania, Aalborg, Danmark and Norden; of German brands Lossius, Stern and Hemmoor have been used. The above mentioned deterioration cannot be attributed to any particular brand of cement.

A portion of the groins runs so far in land that it is only affected by the sea water during heavy storms, and on these portions any deterioration up to the present is hardly noticeable. An other portion of the same groins runs far out into the sea and is therefore, for a great part, under low water, the examining of the condition of the blocks here becomes very difficult; in some cases these blocks have sunk into the sand, and it has been necessary to set new blocks on top of them, so that it has been quite impossible to examine them. In the middle part of the groins, however, the blocks are so arranged that it has been an easy matter to determine the extent of the destructive effect, and it has been just as easy to prove the cause, namely, that the blocks have throughout the summer — in spite of the small

difference of the tides — been exposed to a continual sprinkling of sea water, which in the heat of the sun dryes up and concentrates to a strong brine. In the winter changes often take place from freezing of the wet blocks in the air and thawing in the icefree water of the North Sea.

V a r d o h a r b o u r is located in the Arctic Ocean, at Norways northeasternmost point, over 400 kilometer north of the polar circle and about 2000 kilometer north of Esbjerg. Large harbour works have been erected in the years 1876—1897 on the little Island of Vardo, laying close to the coast (2 kilometer). In the beginning of the work was used a local sand, which contained a quantity of shells, and a local shale, which was crushed to road-metal size. The proportions of mixture was 1 : 3,2 : 6,4.

Already in 1881 it was seen that this concrete was deteriorating so quickly, where it was exposed to the influence of the water and the frost, that it was found necessary to transport sand from a considerable distance and — especially at those points between high and low water — to replace the concrete by a wall built of stone in cement mortar; for this was used a red sand-stone quarried at a comparatively short distance from the harbour. A portion of the western concrete mole, in which the above mentioned shell-sand had been used, had to be completely rebuilt. At those points, where concrete could still safely be used — under low and above high water — the mixture 1 : 1,5 : 3,5 was used; the concrete blocks were painted with a coating of asphalt and tar. The normal size of the blocks was about $6^2/_3$ cubic meter.

The tide at Vardo is normally about 4 meter. The climate is on the whole so cold, that it is only possible to use five summer months as working season. The mean temperature of the air is about 0 degrees centigrade, but the sea is icefree although its mean temperature is close to 0 degrees; the proportion of salt is about the same as in the North Sea namely about $3^1/_2$ pCt.

D e g e r h a m n h a r b o u r is on the Baltic at Kalmar Sound on the south side of the island Øland. As it was only intended to keep the test blocks at Degerhamn free from frost in water, under low tide, the climatic conditions could only have any influence during the hardening of the concrete. The mean temperature of the air can be taken as about the same as at Thyboron and Esbjerg (about 7,5 degrees), and the mean temperature of the water can be taken as almost alike at all three places. The

proportion of salt however is only about $^1/_2$ pCt., in other words, only one seventh of that of the North Sea. The tide in the Baltic is practically unnoticeable.

5. Execution of the mortar trials.

On account of the universal interest in the trials, the »State laboratory for testing materials« in Copenhagen offered to execute the moulding and crushing of the trial cubes, with only the direct out of pocket expences covered, an offer which was very thankfully accepted.

The moulding began in December 1896, and the cubes marked with numbers (written with pencil) and those, with beads moulded in them, sent out in packing cases to Vardo, Esbjerg and Degerhamn one month after moulding. On arrival they were placed in number order in the specially constructed open cases (one set of 77 in each) and then sunk in the sea. As Esbjerg and Vardo harbours are infested with *Toredo nivalis* and other crustaceae, only those cases, that were to be used for the short period trials, were made of deal. For the longer periods, oak cases were used, and at Vardo it was even necessary to make the cases of the — presumably — unassailable Australian Green-heart wood.

A drawing and description of these cases, which have proved to be satisfactory in every respect, will be found in appendices 7 & 8. The cases were especially designed for the conditions at Esbjerg, where they were placed on some piles under the stairs leading down to a little harbour-basin for small boats. It was, however, found that they could be used also at Vardo and Degerhamn without alteration.

The test cubes of »Chaux du Teil« were mixed in the proportions of 3 : 5, 2 : 5 and about 1 : 5 (in reality 23 : 120) which could be taken as corresponding to the proportions of 1 : 1, 1 : 2 and 1 : 3 for the other test cubes.

Until the despatch of the cubes from the State testing laboratory the programme was carefully adhered to, but after that several irregularities occurred, in connection with the cubes for Degerhamn, which from different causes, over which the committee had no control, were not placed in the sea until a year after their arrival. It was decided that these cubes, which were to be placed in water (free from frost), should be kept there for the originally

determined period, so that the first years tests would not come back to the State testing laboratory until two years after moulding; but also on the return journey a similar delay occurred. A mistake of less importance occurred of Vardo, where the ¼ and ½ years tests under the low water level were overlooked, and therefore can be disposed of as a reserve.

In collecting the resulting figures of the 3 months tests, undertaken by Mr. *Wallin* in 1897, no positive result could be arrived at, at so early a stage, except the fact that the English cement and still more »Chaux du Teil« at that period were behind the three other brands in strength. Any influence of the salt water could not be traced, although there was, on an average, found a slightly greater crushing strength for those test cubes, which had been placed at mean tide, than for those that had been kept under low water level. After two years the results were again compared (by Mr. *Ouchterlony* in 1899) but it was found that even then no positive result could be arrived at. First with the ten years tests could any real definite result be given, and it is therefore certain that the irregularities in the commencement of the tests have had no practical effect.

The dates for placing and removing the different test cases, together with the number of these, for each of the three test places, will be found in appendix 9.

At the commencement of the crushing tests at the State testing laboratory (test cubes of up to one year) only three of each 4 cubes were used, while the fourth was kept for an eventual further investigation, this fourth, however, was later crushed to obtain a more reliable average. Both before and after the crushing, photographs were taken of the most characteristic pieces before they were sent for analyses to the members of the committee Messrs. *Buch*, *Lundh* and *Morris Haslinger*.

The chairman of the analysis-committee died, however, in 1898, and amongst his papers it has been impossible to find the articles appertaining to the salt water committee, amongst which were also the analyses of those test cubes, which had been returned up to 1898, especially the Lomma—Limhamn cubes. This is however, of minor importance for the entire investigation, because the first years tests did not — as has already been said — yield any positive result; the death of Mr. *Lundh* has been a severely felt loss to the committee on account

of his great interest in the matter, his ability and personal qualities.

Messrs. *Buch* and *Morris Haslinger* kindly overtook the execution of the sets of analyses which should have been made by Mr. *Lundh*. The analytical results compiled by Dr. *Morris Haslinger*, — including all the »Christiania» tests, — were, however, lost by the fire which in 1898 destroyed the Christiania Cement Works.

From Mr. *Buch*, Aalborg, however, has come to hand a complete analytical investigation, according to the plans of the analysis committee, of all the crushed cubes of »Aalborg» and »Chaux du Teil», together with a portion of the »Nine Elms» cubes (admixture 1 : 2) which were sent from the State testing laboratory.

The investigations up to 1909 comprise all the tests of up to 10 years duration. The remaining tests of 15 and 20 years will in due time receive a similar investigation. In appendix 9 will be found explanation of the handling of these tests. The results of the ten years tests will be found in paragraph 7.

6. Execution of the concrete trials.

The concrete blocks of 0,6 cubic meter (about $0{,}6 \times 0{,}7 \times 1{,}4$ meter) were — with a very few exceptions (a few reinforced cases filled with sand) — moulded on the beach of the North Sea, south of Thyboron canal, close to groin No. 59 where they were to be used. Some of the blocks, however, were only half size, with a length of about 0,7 meter. As a rule three blocks of each kind of cement were made with mortar of proportion 1 : 1, and 1 : 2 and 1 : 3, although the remainder of the cement was occassionally used to mould an additional half or whole block.

Most of the blocks were hand-mixed, very carefully, according to the rules for mixing and stamping, used for the coast protection work. Cement and sand was mixed dry 6×2 times, 3×2 times while water was being added and afterwards 6×2 times wet. The water was pure, but partially salt, as it occurrs at that place. The concrete was stamped in forms made of planed and grooved boards and with wooden bottom. After 1902 some of the mouldings were made by means of a concrete mixing ma-

chine, which, — according to some comparative experiments (made by crushing test cubes of concrete with 20 cm. side line) — mixes the concrete so much better, that the blocks show a greater strength. The blocks were kept moist for four weeks by sprinkling and covering for the sun, after which they were left to harden until opportunity occurred to transport them out to the groin. For the transport of these heavy blocks, weighing about 1400 kilogram, was used a crane running on rails. To facilitate the transport of the blocks a bolt, with the head protruding from the center of the upper side, was moulded in each.

In the table (appendix 10) the mouldings are placed in chronological order from 1896 with the dates of placing in the groin. The plan (appendix 11) and photograph (appendix 12) show the position of the blocks in groin No. 59. Their upper surface is about one meter above mean tide.

Appendix 10 shows, that, besides the moulding in 1896—97 of the fifteen trial blocks (Nos. 1—15) with five brands of cement, used in the mortar cubes, and besides the 24 trial blocks with different kind of sand (Nos. 16—27 and 29—40), several other blocks were also moulded.

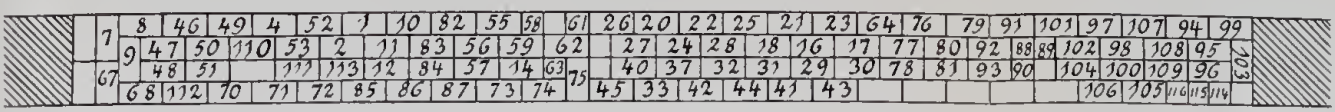
The blocks of »Dania« (Nos. 46, 47 and 48), of Cimbria (Nos. 49, 50 and 51) and of Hellekis (Nos. 52, 53 and 54), which are all normal Portland cements, correspond exactly to mouldings Nos. 1—15, as the mortar mixtures 1 : 1, 1 : 2 and 1 : 3 contain respectively 1350, 675 and 450 kilogram cement per cubic meter sand.

The socalled »Sand-cement« blocks (Nos. 55, 56 and 57) contain an equal proportion Portland cement and pure quartz sand, which are ground together at the works (Aalborg), so that both portions are of the same fineness. One cubic meter sand-cement weighs about 1150 kilogram. For the above trials sand-cement has been measured out as though it were pure cement, so that the mortar in reality contains a comparatively small percentage of cement. The proportions used were one measure sand-cement to 1, 2 and 3 measures of mortar sand, containing therefore, only one measure of binding material to 3, 5 and 7 measures of sand respectively, although one measure hereof is in finely ground condition. These mouldings were repeated in 1901 with sand-cement manufactured of Lomma—Limhamn material (blocks Nos. 79, 80 and 81).

Appendix 11.

Arrangement of test blocks in groin No. 59 at Thyborön 1909.

176 meter from head of groin — 214 meter from head of groin



No.		No.		No.	
1.	Christiania . . . . . 1 : 1	44.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 3	83.	Norden . . . . . 1 : 2
2.	— . . . . . 1 : 2	45.	$^1/_6$C + $^2/_6$F . . . . . 1 : 3	84.	— . . . . . 1 : 3
4.	Lomma . . . . . 1 : 1	46.	Dania . . . . . 1 : 1	85.	Sil. Lomma 1
7.	Aalborg . . . . . 1 : 1	47.	— . . . . . 1 : 2	86.	— 2
8.	— . . . . . 1 : 2	48.	— . . . . . 1 : 3	87.	— 3
9.	— . . . . . 1 : 3	49.	Cimbria . . . . . 1 : 1	88.	Kinnipple . . . . .
10.	Nine Elms . . . . . 1 : 1	50.	— . . . . . 1 : 2	89.	— . . . . .
11.	— . . . . . 1 : 2	51.	— . . . . . 1 : 3	90.	— . . . . .
12.	— . . . . . 1 : 3	52.	Hellekis . . . . . 1 : 1	91.	Tras + cement 1
14.	Chaux du Teil 2	53.	— . . . . . 1 : 2	92.	— + — 2
		55.	Sand cement 1	93.	— + — 3
	16—45 Sand:	56.	— 2	94.	Monier 1 1
16.	$^6/_6$C . . . . . 1 : 2	57.	— 3	95.	— 1 2
17.	$^6/_6$M . . . . . 1 : 2	58.	Tras + cement 1	96.	— 1 3
18.	$^6/_6$F . . . . . 1 : 2	59.	— + — 2	97.	Santorin + cement 1
20.	$^3/_6$C + $^3/_6$F . . . . . 1 : 2	61.	Infus. earth + cement. . . 1	98.	— + — 2
21.	$^3/_6$M + $^3/_6$F . . . . . 1 : 2	62.	— + — . . . 2	99.	— + — . . . . $2^1/_2$
22.	$^2/_6$C + $^2/_6$M + $^2/_6$F . . . . 1 : 2	63.	— + — . . . 3	100.	— + — 3
23.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 2	64.	Sil. Lomma. 1	101.	Neap. Puzz. + cement. . 1
24.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 2	67.	Danmark . . . . . 1 : 1	102.	— + — . . 2
25.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 2	68.	— 1 2	103.	— + — . . $2^1/_2$
26.	$^1/_6$C + $^2/_6$F . . . . . 1 : 2	70.	Slag cement. . . . . 1 : 1	104	— + — . . 3
27.	$^1/_6$M + $^2/_6$F . . . . . 1 : 2	71.	— 1 2	105.	Santorin + lime 1 3
28.	$^3/_6$C + $^3/_6$M . . . . . 1 : 2	72.	. . . . . 1 : 3	106.	Puzzolan + lime . . . 1 3
29.	$^6/_6$C . . . . . 1 : 3	73.	Dania . . . . . 1 : 1	107.	Gypsum free Aalborg 1 : 1
30.	$^6/_6$M . . . . . 1 : 3	74.	Special-brand . . . . . 1 : 2	108	— — 1 : 2
31.	$^6/_6$F . . . . . 1 : 3	75.	— . . . 1 : 3	109.	— — . 1 3
32.	$^3/_6$C + $^3/_6$M . . . . . 1 : 3	76.	Hemmoor . . . . . 1 : 1	110	Infus. earth + cement . 1
33.	$^3/_6$C + $^3/_6$F . . . . . 1 : 3	77.	. . . . . 1 : 2	111.	— + — . . 2
37.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 3	78.	— . . . . . 1 : 3	112.	— + — . . 2^1
40	$^4/_6$M + $^2/_6$F . . . . . 1 : 3	79.	Sand cement 1	113.	— + — . . 3
41.	$^3/_6$M + $^3/_6$F . . . . . 1 : 3	80.	 2	114	Rom. Puzz. + cement . 1
42.	$^2/_6$C + $^2/_6$M + $^2/_6$F . . . . 1 : 3	81.	— 3	115.	— + — . 2
43.	$^1/_6$C + $^1/_6$M + $^1/_6$F . . . . 1 : 3	82.	Norden . . . . . 1 : 1	116.	— + — . 3

In a similar manner, in 1897, — for the trials with tras as admixture to the cement (blocks No. 58, 59 and 60) — finely ground tras (from *Jac. Meurin*, Andernach) has been used, not as an addition, but as an equivalent to a portion of the cement (Aalborg). The finely ground material, cement + tras — which is contained in the mortar mixtures of 1 : 1, 1 : 2 and 1 : 3 — is mixed in the proportion of 1 kilogram cement to 1,28 kilogram tras (i. e. about 1 cubic meter cement to 1,55 cubic meter tras), so that the 25 % (by weight) of free lime contained in the cement, should find a corresponding equivalent of free silica and argillaceous material in the tras. The mortar admixtures 1 : 1, 1 : 2 and 1 : 3 are therefore very poor in Portland cement; if the tras is calculated as sand, the mortars will be proportioned as 1 : 4,10, 1 : 6,65 and 1 : 9,20.

For the trial blocks moulded in 1902 with tras (Nos. 91, 92 and 93) more cement and less sand was used, viz — $^2/_3$ cement + $^2/_3$ tras mixed respectively with 1,2 and 3 measures of sand. If here again the tras is calculated as sand the mortars will be classified as 1 : $2\frac{1}{2}$, 1 : 4 and 1 : $5\frac{1}{2}$. This last named proportion has, for instance, been used by the Copenhagen Harbour board for the works south of the harbour (Sluices at Kalvebod), and is considered as corresponding to cement mortar 1 : 3.

In blocks Nos. 61, 62 and 63 it has been tried, by way of experiment, to use infusorial earth (Mo-Ler) as a chemical admixture instead of tras. This earth occurs on the island of Mors and other places in Denmark, and contains a considerable portion of chemically active silica, namely, in kiln-dried condition, about 70 %, which is found in the form of minute diatomée skeletons. The kiln-dried infusorial earth weighs in dry condition about 275 kilogram per cubic meter, but as it is very hygroscopic, does not feel wet, even when it contains 40 % water.

Of this material $1^1/_3$ cubic meter was mixed with 1 cubic meter Portland cement (Aalborg) and the mixture, in which the infusorial earth should be equivalent to most of the free lime in the cement, has been used for mortar in the proportions of 1 : 1, 1 : 2 and 1 : 3. Calculated according to the proportion of cement only, these can be taken as 1 : 4, 1 : 6 and 1 : 8.

After two years the mouldings were continued in the autumn of 1898 with blocks Nos. 64, 65 and 66, to which Lomma—Lim-

hamn sent a special sample of their Portland cement ground together with 15 % of a silica-rich material.

These samples are found in the table under the name »Sil-Lomma« and were measured as if it were Portland cement, so that the mixtures of 1 : 1, 1 : 2 and 1 : 3, calculated according to the proportion of Portland cement only, would be 1 : $1^1/_3$, 1 : $2^1/_2$ and 1 : $3^3/_4$. As two of these blocks were washed away, three new were moulded in 1901 Nos. 85, 86 and 87.

Three blocks Nos. 67, 68 and 69 were moulded at the same time from cement sent by the cement works »Danmark«, that had then been erected.

In the spring of 1900 three blocks (Nos. 70, 71 and 72) were moulded of S l a g - c e m e n t, manufactured at Esbjerg and weighing about 1100 kilogram per cubic meter. This cement was measured out in the proportions 1 : 1, 1 : 2 and 1 : 3. In the autumn of 1900 the cement works »Dania« sent a sample of a specially burnt Portland cement, which was said to be particularly well adopted to salt water, and of which blocks Nos. 73, 74 and 75 were moulded. At the same time blocks Nos. 76, 77 and 78 from »H e m m o o r« Portland cement were moulded.

From the cement works »N o r d e n«, which had been erected in the mean-time, three blocks Nos. 82, 83 and 84 were moulded in the summer of 1901.

In the summer of 1903 three blocks Nos. 88, 89 and 90, were moulded of Aalborg Portland cement according to the socalled »Kinipple's« method, after which the cement is mixed with a large proportion of water, without any admixture of sand, and then poured through a pipe to the bottom of the form which, filled with stones and sand, is standing in the sea, so that the influx of liquid cement gradually drives out the water from all the crevices. On this occasion the blocks were taken up from the sea after 24 hours and placed on the land to harden before being again placed in the water. Two of the blocks were moulded with ordinary shingle-ballast used for concrete and the third with a finer ballast.

In 1903 three hollow »Monier« blocks Nos. 94, 95 and 96 were ordered from a cement-ware firm in Esbjerg, containing the mortar mixtures of 1 : 1, 1 : 2 and 1 : 3, of the same size as the other test blocks and at the same time containing a little hole, through which, after they had been transported by rail and waggon to the coast to groin No. 59, they were filled with sand. In

Appendix 12.

Concrete blocks in groin No. 59 at Thyborön.

filled condition they were removed by the crane and placed in the groin. No damage occurred to the blocks during transport. The hole was filled up with concrete.

The surface of these Monier blocks has, as the other blocks of 0,6 cubic meter, an area of 4,5 sq. meter. The thickness of the walls is only 7 cm., the concrete mass is equal to 44 % and the sand filling to 56 % of the whole volume. The reinforcing iron (5 mm. round iron with 10 cm. spacing) weighs 11 kilogram.

In the autumn of 1903 four blocks, Nos. 97, 98, 99 and 100, were moulded of Aalborg Portland cement mixed with an equal quantity of »Santorin earth« purchased from the firm of Scaliery, Vitalis and Co., Athens, and used as received without being ground. The mixture was used as »cement« for mortar in proportions 1 : 1, 1 : 2¼ and 1 : 3 which, if calculated according to the contents of cement only, would be as 1 : 3, 1 : 5, 1 : 6 and 1 : 7. Another block, No. 105, was moulded without cement and sand, the mortar being made of one measure slaked lime mixed with three measures »Santorin earth«.

At the same time quite similar blocks, Nos. 101, 102, 103 and 104, were moulded of white Puzzolan from Naples, purchased from Messrs. Luigi Mosso, Naples, and block No. 106 moulded of lime and Puzzolan, the Puzzolan being used without being ground.

In the summer of 1904 blocks Nos. 107, 108 and 109 were moulded of »Aalborg« Portland cement, ground without any addition of gypsum (quick-setting) similar to that used in the last few years for work on the groins.

Finally in the summer of 1906 the last blocks, Nos. 110, 111, 112 and 113, were moulded with cement in the usual, fairly rich, proportions to sand, viz: — 1 :1, 1 :2, 1 : 2½ and 1 : 3 but in such manner that 40 % air-dried and finely ground infusorial earth (Mo-Ler), similar to that used with the poor mixtures in blocks Nos. 61—63, was added to every 100 kilogram cement. This quantity, with its contents of about 28 kilogram silica, should be about equivalent to the quantity of free lime in the cement (abt. 25 kg. CaO).

In 1906 Roman Puzzolan of two kinds, red and black, was used for blocks Nos. 114, 115 and 116 (with respectively black, red and black Puzzolan). The binding material for these blocks was composed of equal parts of Puzzolan and Portland cement,

so that the mixtures 1 : 1, 1 : 2 and 1 : 3, if calculated according to the cement only, must be called 1 : 3, 1 : 5 and 1 : 7.

The incommodities that have occurred, in the course of years, at the place where the trial blocks were kept, can only be regarded as normally occurring to concrete used in coast or harbour work. In the winter of 1899—1900 the foundations of the blocks sank from ½ to 1 meter, as the sand had been washed away from under the blocks. In the spring of 1900 they were again re-set to their original height by moulding a layer of concrete on the foundation. In the following winter 1900—01, 23 of the test blocks were washed away during a storm and disappeared in the sandy bottom, and not until a number of new blocks had been moulded to replace them in 1901, so much of the sand that covered the lost blocks was washed away, that 14 of them (Nos. 14, 24, 37, 32, 33, 37, 40, 55, 56, 57, 58, 59, 62 and 63) could be raised and replaced in the groin; in consequence hereof those, that were moulded to replace them, are duplicates. The remaining nine blocks (Nos. 13, 15, 19, 35, 38, 39, 60, 65 and 66) have not since been recovered. Some of the above mentioned blocks (Nos. 13 and 15) had already then, after four years, shown such clear signs of deterioration that it was without interest to continue the trial with them. No. 60 could not be replaced, there being no tras available. The remainder were replaced by the new Nos. 28, 42, 44, 45, 86 and 87.

Since this a few blocks have been washed away, namely two blocks (No. 34 and 36) which have not since been recovered, and for which two new blocks (No. 41 and 43) were moulded in June 1902; and one block (No. 4) which was washed out from the groin in the winter of 1908—09 but which will be replaced. None of the blocks that have been washed out have shown any signs or damage, from this cause, when recovered.

The blocks are repeatedly inspected, and in 1900 an analysis (at Prof. V. Steins laboratory, Copenhagen) was made of portions taken from eleven blocks, which already in December 1899, after they had been placed over two years in the groin, had begun to deteriorate. Several other blocks have since then deteriorated and this is — as may easily be supposed — especially those, which contained the poorest mixture (1 : 3) of the cement in question.

The conditions at the place of testing have answered exactly to what was required, namely to expose the blocks to the same

conditions under which the concrete in the groins has been destroyed. The test-blocks that have been attacked have shown exactly the same appearance as the other concrete in the groins, especially at the commencement when the first signs of deterioration show themselves as hair-fine cracks, through which a white mass exudes.

It may be remarked here, that opportunities have occurred to notice a similar white substance exuding from the concrete in the groins, although not on the test blocks themselves, in the form of vertical and growing hollow stalks: the similarity to plant growth has earned for them the name of »concrete tulips«.

In 1906 they were observed on a concrete mass moulded in a dry trench on the beach, which was to form a portion of a groin, when the trench quickly filled with salt water, which had percolated through the strand sand. It is not necessary to enter into an explanation here, of this, at first sight, extraordinary occurrence, as it has quite recently been discussed in the periodical »Zement und Beton« for 1909 pp. 149—154 (with figure pp. 218).

7. Results of the mortar trials.

For the valuation of the deterioration from which the mortar cubes have suffered, the results obtained by the crushing tests will, undoubtedly, be of the greatest importance. At the same time, the — equally interesting — chemical analysis of the mortar, meets with certain difficulties as the proportion of mixture of the binding material with sand — although it is fairly well known — can not be determined sufficiently accurate for this purpose.

A third point to judge from, will be the inspection of the cubes immediately before and after thee above named mechanical test. As an assistance on this point, a number of photographs have been taken of the cubes.

The material upon which the judgement must be based, will be as follows:—

Appendix 13. The State laboratory's investigations of the five kinds of cements used for the mortar cubes, together with Mr. *Buch*'s tensile tests with Aalborg cement.

Appendix 14. Table of the results of the crushing test of the mortar cubes after $^1/_{12}$, $^1/_4$, $^1/_2$, 1, 2, 4, 6 and 10 years.

Appendix 15. Graphic review of same.

Appendix 16. Results of the analyses of the crushed cubes.

Appendix 17. Photographs of some of the cubes.

From appendix 13 it will be seen that the cements were slow setting with the exception of »Nine Elms« which set in 14 minutes, under a fairly high increase of temperature (11,4 degrees C.) and at the same time, in the standard tests, showed only one half or one third of the strength of the other three kinds of Portland cement. During »Erdmenger's boiling test« — of samples, three days old, boiled for six hours under 10 atmosphere's pressure, — the »Nine Elms« cement boiled to pieces, whilst the other three Portland cements registered an increase in strength of 50 % for tensile tests, and about 150 % for crushing tests.

»Chaux du Teil« also showed good testing results — especially a good increasing strength — also with Erdmenger's test, although the strength in the beginning was small, on account if its slow setting qualities.

The series of tensile tests with the three cements, kept in fresh water (at the foot of appendix 13), show that they have gradually and regularly increased in strength, even up to the ten years tests. The table in appendix 14 shows that a large proportion of the ten years cubes and also, to a certain extent, the shorter period cubes, have been lost, especially at Vardo at mean tide. The few remaining test cubes have, however, shown an extraordinarily high strength, which would suggest that the interior of the mass had not been attacked. That the destruction of the cubes principally is due to the crumbling away of the outer shell can also be seen in the photographs in appendix 17. These incomplete test-results are therefore in appendix 15 — in the square containing the Vardo results at mean tide — given by a thin line. In the square for the under-water tests from Vardo, the ¼ and ½ year tests, which are missing, have been substituted by the one months tests from the State laboratory for testing materials so as to complete the curve. It will also be seen from appendix 15 that, as a rule, the strength has reached a maximum within the first year, afterwards, in the course of two years time, it drops to a minimum and then again increases. The decrease is therefore of no practical importance. This development seems to take place slower at Vardo, which may perhaps be explained by the influence of the lower temperature there. The tests under low water have — as was expected — kept better than those at mean tide;

the shape of the curves are also more even. This difference is greater at Vardo than at Esbjerg; at Degerhamn the curves are the most even.

As the first test periods, which followed so quickly after each other, have not brough any important results, it would most probably have been better not to have included the ¼ and ½ year tests, and perhaps even the one years, so that a greater amount of material could have been available for the later tests, especially those of 10 years and upwards.

In order to follow the chemical effect of the salt water on the mortar, several analyses have been made of the mortar cubes from Esbjerg, which, in appendix 16, have been arranged such, that the contents of lime is expressed by the figure 100. It will be seen that the sea water has had no effect, so far, on Aalborg cement, while on the other hand, the poorer mixtures of Chaux du Teil show an increased quantity of magnesia and sulphuric acid. At the same time the quantity of lime has decreased, which is shown in the table by the increase of the proportions of soluble silica and of R_2O_3 (iron and clay). This proved also to be the case with the analysed outer shell of the »Nine Elms« cubes 1 : 2. Finally the table shows, for all the tests, a conspicuous general increase of the quantity of chloride, which — according to the analyses — is usually not combined with alkalies.

It was not expected that the analyses of the tests from Vardo would show such clearly defined results as the corresponding tests from the warmer air and water at Esbjerg. An analysis of a single test cube, which after four years at mean tide at Vardo could only be identified as Chaux du Teil, admixture 1 : 5 (poorest mixture) by the glass beads which were moulded in it, showed, however, — quite contrary to expectation, — a very great chemical alteration, as the contents of sulphuric acid and especially magnesia had increased to a great extent at the same time as the lime had sunk to about $^2/_3$ of the original quantity.

The difference between the natural conditions at the three test places, Esbjerg, Vardo and Øland, and the difference between placing of the tests above or below water at the two first mentioned places, has the effect that the results can be separated out on several points, for such cubes which have been subjected to the same influences, except on one point, the cause of which, therefore can be traced. Of these causes shall be named: —

Mean temperature of the water.
Mean temperature of the air.
Daily change of temperature (frost and sun drying) both at Esbjerg and Vardo;

besides the always existing difference in the quality of the sand, the kind of cement and the proportion of cement in the mortar.

Besides this it could be expected that information might be gained of the influence of the percentage of salt in the water (Degerhamn ½ %, Esbjerg about 3½ %) by compairing the tests from Degerhamn and Esbjerg, but on account of the irregularities that occurred with the tests sent to the first named place, this has however, been made more or less impossible.

Mean temperature of the water, at Esbjerg 7 degrees C, Vardo O, degrees C. This difference has had the effect that the mortar at Esbjerg has maintained a greater strength than at Vardo, which can be seen by comparing the tests placed under low water from both places.

The mean temperature of the air — (in Esbjerg 7½ degrees C, in Vardo O degrees C)—but probably still more the frequency of freezing temperatures is seen to have had a great effect on the samples, as nearly all the Vardo samples at mean tide have been destroyed. It must be remembered that these samples during frost periods are frozen and again thawed by the water twice daily .It is also possible, especially at Esbjerg, that the concentration of the salt water, and the drying by the sun during low water may have produced injurious effects, but at the same time the warmth will have been favourable to the mortar by helping it to harden.

The quality of the sand. The tests with strand sand, especially the mortar mixtures 1 : 2 and 1 : 3, are somewhat weaker than the corresponding with normal sand, although they have otherwise stood just as well.

The quality of the cement. It will be seen that »Chaux du Teil» in the strongest mixtures has only reached a strength, equivalent to Portland cement's weakest (1 : 3), and the weakest mixture of »Chaux du Teil» was, already after two years, completely destroyed by frost at mean tide mark of Vardo. That »Chaux du Teil» stands well in the Mediterranean waters in spite

of the greater percentage of salt in the water, is without doubt explained alone by the absence of frost as well as tide; this corresponds well with the experience with other comparatively weak mortar mixtures in these districts, for example the Italian Puzzolan mortars of which it is known that their consistency after twenty years can only be compared with chalk or soft limestone, what, however, does not prevent the use of these mortars with advantage in the Mediterranean.

For Portland cement it will be seen that the proportion of 1 : 2 gives results which come closer to the stronger mixture of 1 : 1 than to the weaker 1 : 3, although 1 : 1 is the only mixture for which cubes are available after the 10 years at mean tide at Vardo.

8. Results of the concrete trials.

A mechanical investigation of the concrete trial blocks, of the same kind as the crushing of the cubes in a machine, is not possible, and the chemical analysis of the concrete can only be used with great care on account of the great proportion of sand and stones, and even more so because it could well be imagined that foreign matters might unintentionally have been mixed with the stone admixtures. The investigation of the block trials must therefore chiefly be based upon observation of the blocks, cracks or superficial destructions, and on what results can be gained by a mechanical investigation by blows or scraping.

As all the blocks have been laying at the same trial place, groin No. 59 at Thyboron, no material is obtainable from these trials as to how the same kinds of concrete would have behaved under other conditions. It may, however, safely be stated, that concrete made of the materials here used, so carefully mixed, and with the same proportions between cement, sand and stones, even as the poorest of the mixtures used (1 : 3 : $5^1/_8$), when used under ordinary conditions either in the air, in the ground or in fresh water, would — practically speaking — last for ever. What can be judged by the trials will partly be the general influence of the local conditions, — in other words, — the salt water, the daily sun drying in the summer and the influence of frost in winter — and partly the varying conditions introduced in the moulding, viz: quantity of cement in the mortar, quality of the cement, the different admixtures to

the cement, various degrees of fineness of the sand and special conditions as Kinnipples method of moulding etc.

For a judgement of the results of the block trials the following sources are available.

Appendix 10. (above mentioned) Table for mouldings together with remarks concerning the condition of the blocks in 1909.

Appendix 13. (above mentioned) Laboratory tests of the cements used in the mortar cubes.

Appendix 18. Laboratory tests of some of the cements used.

Appendix 19. Graphic review of the conditions of the 24 sand blocks.

Appendix 20. Table of crushing tests with concrete cubes.

Appendix 21. Analysis of concrete samples, year 1900.

The cements, which were used besides the five named in appendix 13, were quite normal Portland cements except where it is remarked that certain additions have been made. Appendix 19 shows in the same manner as appendix 6 the admixtures of sands used respectively in mortar 1 : 2 and 1 : 3. The condition of the blocks are shown by a circle, the area of which is the smaller the more corroded the block is; their numbers, taken from Appendix 10, are given. As some of the blocks, especially with mortar 1 : 3, were moulded later than the others, the date of the year is given for these.

Appendix 20. The crushing tests for concrete were made with cubes of about 20 cm in size — for the greater part with only one test cube. Only four of the results are average of several (5) tests; namely the special series consisting of »ordinary cement« and »gypsum free cement«, »hand mixing« and »machine mixing«. Of the remainder only single test cubes have been moulded, as the mixtures in question could not be expected to give result of any great practical value.

In appendix 21 will be found, — on top of the page, — what can be taken as the original contents of lime, magnesia and sulphuric acid in the samples, before the admixture of water. By comparing these figures with the results of the analyses — which also give the quantities of chloride — it will be found that the proportions of magnesia and sulphuric acid have been increased three or four times, for the mixture with infusorial earth (No. 63) even still more. These additions must have been taken up from

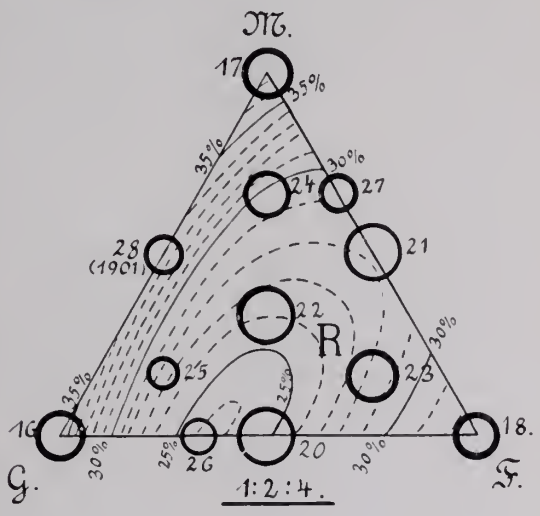
Appendix 19.

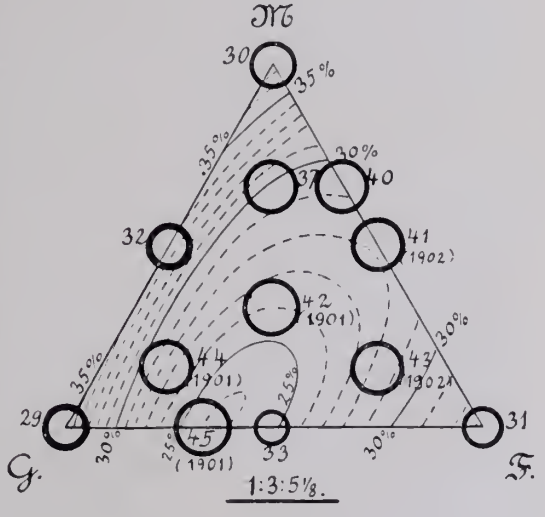
Concrete tests with sand of different fineness at groin No. 59 at Thyborön.

In the two figures below, both of which show the porousness of the sand admixtures, given in appendix 6, by the curves, the moulded blocks are designated with a number, by which they will be found noted in the moulding table, appendix 10. The first figure contains the blocks with the proportions 1:2:4 and the other with 1:3:5½.

The conditions of the blocks are marked by a circle, the radius equalling the quality shown in appendix 10.

Most of the blocks were moulded in 1896—97; for those that were moulded later, the year is affixed in brackets.





the sea water. If a smaller quantity of CaO has possibly been lost, is impossible to determine. The quantity of chloride, which comes from the sea water, does not, — for the greater part of the tests —, appear to be greater than, that it can be the result of the samples being saturated with salt water.

The uncertainty, which is always attached to a series of tests, as those in appendix 10, — which only contain a single sample of each class —, is increased in this case by the fact that certain blocks during storms (which — as already mentioned — have been able to throw the blocks out of their place), can have been damaged by collision with drift timber or other blocks without being moved themselves. But if the blocks of the same composition, either with reference to the class or quantity of cement, develope in the same manner, so that for instance the richer mixtures of cement first begin to suffer, after the poorer mixtures are badly deteriorated, it can hardly be due to any unaccountable reason.

The quantities of cement in the mortar.

It will be seen from the tables that blocks Nos. 3, 6, 9, 12, 15, 51, 54, 57, 69 and 72, which are all of mortar 1 : 3 are wholly or partially, so destroyed that it can be concluded that this mixture, corresponding to 450 kg. cement per cubic meter strand sand, must not be used for work in sea water. These trials, however, do not give any information as to the correct proportion of stone in the blocks, as the blocks have been moulded with a proportionally large quantity of mortar. It can be presumed that a closer skeleton of stones (in other words, a larger proportion of stones) would possibly have made the blocks more insusceptible to attack.

It will also be seen that with the mixture 1 : 2 several blocks have been destroyed or attacked, namely blocks Nos. 2, 5, (14), (56), (59), (62) and (71), although for the numbers in parenthesis, this can be due to the fact that Portland cement was not, or only partly, used as binding material; hereof further will be found later. The mixture 1 : 2, corresponding to about 675 kg. cement per cubic meter strand sand, can therefore, as yet, be supposed to contain sufficient cement. Of the mixtures 1 : 2½, corresponding to 540 kg cement per cubic meter strand sand, which was only used for blocks Nos. 99 and 103, (which also have certain additions to the cement), no information is obtainable from these

experiments or from the groin work at Thyboron, where this proportion is used, but only has been in use for eight years, without being too poor, — as far as can be judged as yet.

The quality of the cement. While the mixture 1 : 3 — according to what is said above — must be considered too poor for all the cements, taken as one, a difference in quality of the different brands can only be ascertained, if the mixtures 1 : 1 and 1 : 2 in twenty years time will yield material hereto. Blocks Nos. 13 and 14, 55 and 56, 58 and 59, 61 and 62, 70 and 71, give well reason for doubt, but as the cement in most of them has received some addition, this doubt ought not to lead to any anxiety in the use of good Portland cement, in suitable mortar mixtures, (presumably 500 to 600 kg. per cubic meter sand) for work in the sea.

Admixtures to the cement.

It has already been said that several of the admixtures, tried with the cement, have on the whole had an unfavourable effect (blocks 55 and 79, 58, 61, 70 and 91), whereas on the other hand, other special mouldings (blocks 64, 73, 97, 101 and 107) are, up to the present, undamaged, perhaps though only because several of them are of later date. For the older of them, however, even the richest mixtures (sand cement No. 55. Tras No. 58 and infusorial earth No. 61) are in reality quite weak. It is therefore — technically seen — a good result that block No. 55 is not — as most of the blocks 1 : 3 — already quite destroyed. It is another question if this mixed mortar can be made as cheaply as Portland cement mortar 1 : 3 or 1 : 2½.

The only reference to those blocks that are not yet ten years old, will be found in the table (appendix 10).

The variation of the fineness of the sand has shown very marked results in the mixture 1 : 2, whilst the results for the mortar 1 : 3 are uncertain, as most of those blocks, which could be expected to be of great interest, have been washed away. Of mortar 1 : 2, on the other hand, only a single block (with equal parts coarse and medium, but without fine sand), has been washed away, and the block that replaced it has shown results which correspond well with the others. It will then be seen that of the unmixed classes of sand (C, M and F) the fine sand (F) has been unfavourable; this agrees with what has already been said about this sand being far behind the coarse »normal

sand». The use of about one half of fine sand and the rest coarse or medium, — preferably both mixed —, can be expected to produce the best mortar, corresponding to the result marked »R« in the diagram (appendix 19).

This result must be called rather unexpected, as it could be expected, according to the closeness of the sand mixture, that block No. 26, where the spaces in the sand are only 24 %, would be the most durable, and from experience from other places it could be thought that block No. 27 would prove to be especially good. Both these blocks contained $^1/_3$ fine and $^2/_3$ of coarser sand of equal fineness, respectively coarse and medium.

Amongst the different conditions which there has been opportunity to investigate here, it may be added that the test blocks from 1896 were trowelled on one half of the upper surface, without, however, any advantage herefrom being seen.

The mouldings that were made according to Kinnipples method (pure cement, moulded under water) seem succesfull. The »Monier« blocks also seem to give good results, but their practical use will depend on their price and also in many cases — as for instance for coast protection work — on the question whether these hollow blocks will resist the action of the breakers and the impact of pieces of wreck etc.

9. Summary of the results.

From the foregoing articles the following shall here be emphasized:

a. The tests were carried through in such a manner that only the commencement and termination were referred to the laboratory; this gives them additional practical interest.

b. The case constructed for the test cubes has proved to be advantageous in guarding them against mechanical injury without excluding other physical effects.

c. The marking of the test cubes with coloured glass — in the form of beads or pieces of broken glass — to determine the proportions and classes of cement, has been satisfactory.

d. In planning out the experiments, the test periods should not have been fixed so short in the first year, so that more material could have been available later.

e. The chemical action of the sea water alone is not able to destroy the mortar, as the Portland cement appears to be more or less unaltered.

f. On the other hand a greater chemical alteration is proved with »Chaux du Teil«. From the single analysis, from Vardø, it would appear that the destructive mechanical influence may have assisted the, simultaneously working, chemical destruction.

g. The destruction of the mortar is for the greatest part due to the mechanical influence of the frost.

h. The destruction of the concrete blocks is also sufficiently explained by the climatic influences.

i. The mortar mixture 1 : 3 is too poor for sea water in Scandinavian climates.

j. The sand used for the mortar should be a mixture of sands of different fineness although a larger proportion ($^1/_3$ to $^2/_3$) should be line; it is not the closest mixture which has stood the best.

k. The addition of a finely ground material to the cement is advantageous (Tras or even sand).

It has been the intention with this paper to publish the plans for the experiments and the results, which have been obtained after a lapse of ten years. When these results are few and small, it is to a certain extent due to the fact that the tests are only half finished, as they, according to the plan, are intended to last over a period of twenty years. It would even have been more satisfactory if the experiments had been planned to last for a still greater number of years.

Appendix 1.

Minutes

of the meeting of the Scandinavian Portland cement Manufacturers, Copenhagen, 7th April 1896.

(Appendix D. II): The committee for the investigation of the influence of sea water on Portland cement, shall be formed for the following purposes:

a. To acquaint itself with the existing literature with bearing on the subject. The committee will be at liberty to purchase — for the means of the Society — such literary works, which are not obtainable from the libraries of the official testing laboratories.
b. At Aalborg Cement Works and on Denmark's and Norway's West Coasts, to study the influence of sea water on cement samples exposed to the influence of the water.
c. By the expected assistance from the authorities in Denmark and Norway to use for investigation purposes, parts of the coast protection works along the west coast of both countries.

The committee shall have free hands to deal with the questions which are here outlined. It is asked to apply to the Society for the necessary means for carrying out its work. No time is fixed for the completion of the work of the committee.

The following gentlemen were proposed as members of the committee:

A. Poulsen, Esq., Engineer, Lemvig.
K. Buch, Esq., Engineer, Aalborg.
A Norwegian Harbour or Lighthouse Engineer.
J. W. Lundh, Esq., Engineer, Hellekis.
B. H. Wallin, Esq., Engineer, Gothenburg.

Copenhagen, the 7. April 1896.

R. F. Berg. *Otto Hillfors.* *D. Berg.*

Appendix 2.

Report

of the meeting of the Society of Scandinavian Portland cement Manufacturer's Salt water Committee in Copenhagen June 1896.

On Saturday the 13. June 1896 at 10^{30} a. m., the Salt Water Committee held a meeting at the Faxe-Limhamn's offices, St. Annæ Plads, Copenhagen. All five members of the committee were present, viz:

K. Buch, Esq., Aalborg Portland Cement Works.
Dr. *M. Haslinger*, Slemmestad Portland Cement Works.
J. W. Lundh, Esq., Hellekis Aktiebolag.
A. Poulsen, Esq., of the office of harbours and coast protectection in Denmark, and
B. H. Wallin, Esq., Laboratory for testing Materials, Gothenburg.

The invitation to the meeting had been sent by *A. Poulsen*, Esq., who thanked the members for their attendance, and gave the information that it could be expected that the Director for the Norwegian Harbour Board would soon point out a harbour engineer, who would then join the committee as a sixth member, he also proposed that a chairman to the committee be elected.

A. Poulsen was then elected chairman, and thanked the members for the honour.

The chairman informed the members that, besides the proposal for arrangement of the tests, which he had sent to each member, additions and alterations to the same had been received from Messrs. *Buch* and *Lundh*. On the basis of these proposals the following points were agreed upon:

1) The number of different cements to be used for the trials.

In order to compare the Scandinavian cement with cement from other countries, it is decided to try one French and one English cement, chosen from those brands, which are considered to be especially well suited for use in sea water, and furthermore has been used for the outer surfaces of concrete blocks. Of the English cements a brand is to be chosen, which has proved satisfactory, when tested in the North of England or Scotland, where the climate, as near as possible, is similar to Scandinavia's.

Of the French cements, it is decided to use the brand »Teil«. The arrangements for procuring the requisite French and English cements will be undertaken by the chairman and Mr. *Wallin*.

It is considered unnecessary to include a German cement in the trials, on account of the similarity between the products of the Scandinavian and German cement Industry.

In order to limit the extent of the trials it is decided to test only one Danish, one Norwegian and one Swedish cement.

As only one Norwegian cement works, Slemmestad, exists, this was of course taken.

In Sweden are four cement works, namely Hellekis, Lomma-Limhamn, Visby and Oland, of these Hellekis and Visby can to a certain extent be considered represented at the trials, when the product from Slemmestad is tested, as the method of manufacture is the same, (dry process, hard lime stone and fine grinding). Oland only differs from these in respect of the fine grinding, and — from its situation — must be taken as not greatly interested in salt water tests. It is therefore decided to choose Lomma—Limhamn as the Swedish brand, as the method of manufacture (wet process, soft lime stone and fine grinding) has several points of difference from the other three Swedish brands.

Three cement works are found in Denmark, namely Aalborg, Cimbria and Dania, all — according to the method of manufacture — closely related to Lomma—Limhamn, most perhaps Dania. For the trials Aalborg is chosen. This brings the total number of cements to be tested up to five. As shown below, one of these will be tested with two classes of sand, making in all six test series.

2) Duration of the trials. — The test samples to be kept one month after moulding under favourable hardening conditions (moistened) and afterwards in water at the trial places. Samples

will be taken up for testing after the lapse of 3 and 6 months, 1, 2, 4, 6, 10, 15 and 20 years. This will make nine series of tests; as tests will also have to be made one month after the moulding the total number of this kind of series is brought up to ten.

3) Proportion of cement in the samples. The mortar will be mixed with 25 %, 33$^1/_3$ % and 50 % of cement. Besides these a few cubes will be moulded with neat cement (100 %) making thus a little over three (about 3$^1/_4$) series of tests.

4) The trials to be executed, partly with mortar cubes, having the normal shape for crushing tests (50 cm. cross-section) and partly by moulding some large blocks of concrete for observation, and by investigating old concrete.

5) The mortar tests to be so arranged in salt water, that they, with each tide, come below water and again out of it, so that they are subjected to the influences of weather and frost. These tests to be arranged as free as possible. Other mortar tests to be arranged in salt water below the lowest water mark, placed in cases. Furthermore samples are to be placed in fresh water or in the Baltic at Øland. It is left in the chairmans hands to work out a sketch showing the method of placing the samples, according to what would be agreed upon, especially with a view to the conditions at Esbjerg boat harbour, as the chairman has obtained permission from Mr. *Otterstrom*, director of the office of harbours and coast protection, to make use of the very favourable conditions of this place; the resident engineer to the office of harbours and coast protection, harbour engineer Mr. *Westergaard*, has also promised to assist the committee.

It is left to Mr. *Wallin* to obtain information through the experienced Norwegian colleague cand. *Simonsen*, respecting the possibility of arranging the tests in one of the northern Norwegian harbours, where the requisite piles are found, under similar conditions as at Esbjerg.

A similar task, with reference to the arrangement of tests at Øland or another place on the Baltic, is undertaken by the chairman by application to the Øland Cement Aktiebolag.

As — according to the arrangements — tests shall be made at Esbjerg, a northern Norwegian harbour and at Øland (the water at this latter place being so fresh, that it is considered un-

necessary to undertake trials with quite fresh water), there will be three sets of tests.

6) Larger concrete samples are to be placed — as proposed by the chairman — at that portion of Jutlands west coast, that is in charge of the Lemvig department of the office of harbours and coast protection, the chairman having obtained sanction from the director of the named office to execute the mouldings and undertake the placing of the blocks at a suitable place. It is understood, however, that the harbour and coast protection office will be supplied with the necessary cement, free of charge. It is left to the chairman to work out a detailed plan for the concrete trials, which shall consist of at least one block of each brand of cement (Point I) and of each class of mortar (Point III), or — in other words — at least 15 blocks. For the moulding of these shall be used the ordinary material used for concrete work at the North Sea coast near Thyboron canal; that is, sea water, strand-sand and ballast.

7) Samples are to be procured for investigation and analysis, together with information as to methods of manufacture and destruction of older concrete structures, which have been destroyed by sea water in connection with the influence of inclement climates. Dr. *Haslinger* undertakes to apply to the Norwegian Harbour Board for information respecting some structures at Vardo and other northern harbours, which are understood to have been destroyed in this manner; the chairman undertakes to procure similar information respecting concrete structures destroyed at Esbjerg and at other places on the West coast of Jutland.

8) Of the mortar tests, three are to be moulded for crushing tests and one for analysis or reserve, altogether four for each test, all with a cross section of 50 cm □.

9) All the mortar cubes are to be moulded and afterwards tested at the same place in order that a reliable comparison of the results can be made. The mouldings can be made with either salt or fresh water, although preferably with salt water, which the chairman undertakes to send from the North Sea near Thyboron canal. The tests to be kept for one month under favourable conditions (moist, but not placed in water) at the place of moulding.

The moulding and testing shall preferably be undertaken by

the laboratory for material testing at Gothenburg. It is left to Mr. *Wallin* to apply for reduced charges.

The test pieces to be sent from the testing laboratory to the three trial places packed in wooden boxes with wet sea-weed as packing.

10) Sand. All five brands of cement for the mortar tests to be moulded with normal sand, and also one of them with North Sea sand, of which the chairman undertakes to send a quantity of the kind generally used for the West Jutland coast protection work, and corresponding to that, which is used for the concrete block tests.

As normal sand is to be used the quality manufactured on Bornholm.

11) Marking the samples. The mortar samples to be stamped with a number, the same number being later written on with blue chalk, and noted in a register in which is also noted information as to the place occupied in the test cases for the sea water tests. Besides this, at least twenty small coloured glass beads are to be mixed in the body of each piece, when it is being moulded, so that each of the five brands of cement — together with the strand-sand series — is identified by its special colour of bead; the three different proportions of cement are indicated by the size of the beads.

The concrete blocks are to be marked by stamping the galvanized iron handle, moulded in the block, and also with glass beads, as mentioned above.

12) Before moulding, a complete analysis is to be made or each of the five brands of cement; which analysis shall be undertaken by the respective works.

After the crushing tests the broken pieces are photographed and an analysis is made partly of the interior and partly of the outer surface, in order that, as far as possible, an analysis will be obtained of what can be seen to have been altered by the influence of the sea water, and what appears to be still in good condition. By these analyses shall be determined the contents of silica, R_2O_3, lime, magnesia, sulphuric acid and carbonic acid.

Appendix 3.

Marseille, le 11. Juillet 1896.

Monsieur l'Ingénieur en Chef et Cher Collègue,

J'ai l'honneur de vous accuser réception de votre lettre du 2 de ce mois relative aux essais comparatifs que vous vous proposez d'entreprendre sur les ciments de Portland de diverses provenances et en même temps sur les chaux du Teil, au point de vue de la résistance à l'eau de mer.

Vous savez que des essais sur la résistance des mortiers ont été entrepris dans un grand nombre de ports et ont déjà fourni des résultats très intéressants.

A Marseille, nous nous livrons à des essais de ce genre depuis 1853; mais ces essais ont été limités au point de vue pratique spécial à ce port. Ainsi, nous savons très bien que certains ciments et notamment des ciments de Portland donnent à la mer de très bons résultats et fournissent, dans les premiers temps, une résistance beaucoup plus grande que les mortiers de chaux. Mais la chaux nous coûte seulement un peu plus de la moitié du prix auquel nous obtenons les ciments de Portland; elle nous donne des résistances très suffisantes; son poids est de 750 kg au mètre cube, tandis que le poids des ciments de Portland est de 1150 kg au moins; de telle sorte qu'avec un poids de chaux bien inférieur on obtient de la même compacité dans les mortiers.

L'emploi de la chaux est donc pour nous très économique; tous nos travaux sont exécutés avec la chaux hydraulique du Teil; nous n'employons les ciments de Portland et autres que dans des cas exceptionnels, lorsque nous voulons obtenir au bout d'un temps très court une grande résistance. Nos essais portent donc principalement sur les chaux.

Les essais comparatifs que vous pourrez faire sur les ciments de Portland et les chaux du Teil n'auront sans doute pour le Danemark qu'un intérêt purement théorique, parce que la chaux du Teil coûterait dans ce pays beaucoup plus cher que le ciment.

Nous exigeons pour les briquettes de chaux pure une résistance à la traction de 3,5 kg par centimètre carré au bout

de 7 jours, et de 5 kg au bout de 14 jours. Pour les ciments de Portland, la résistance exigée est de 20 kg à l'expiration du 7e jour et de 35 kg à l'expiration du 28e.

La chaux hydraulique du Teil que nous employons provient des usines du Teil (Département de l'Ardeche), de la Société *J. & A. Pavin de Lafarge*, à l'exclusion des chaux des autres marques appartenant à cette Société et de toutes autres chaux.

Le dosage que nous employons couramment est de 350 kg de chaux blutée par mètre cube de sable non tassé. Quand nous voulons des mortiers étanches, quand, par exemple, nous construisons des bâtardeaux en béton de chaux coulé frais dans l'eau, nous portons la quantité de chaux à 400 kg par mètre cube de sable.

La chaux blutée livrée en sacs pèse de 750 à 800 kg le mètre cube. Le dosage à 350 kg est donc un peu plus faible que celui qui comporte 1 de chaux pour 2 de sable.

Pour des mortiers de chaux destinés à être successivement baignés par l'eau de mer, puis exposés à l'air libre, comme il arrive dans des mers à marées ou dans des bassins de radoub, par exemple, il est important d'avoir des mortiers bien compacts; je crois que, dans ce cas, il convient d'adopter le dosage à 400 kg.

Il en est de même pour des mortiers exposés à l'eau et à de très grands froids; je recommanderais, dans ce cas, le dosage à 400 kg.

Je suis entièrement à votre disposition pour tous autres renseignements.

Je vous serai très reconnaissant de me faire connaître les résultats de vos essais.

Veuillez agréer, Monsieur l'Ingénieur en Chef et Cher Collègue, les assurances de ma considération la plus distinguée.

Guérard,
Ingénieur en chef du port de Marseille.

A Monsieur l'Ingénieur en Chef des Travaux hydrauliques de l'État, Lemvig (Danemark).

Appendix 5.

Scheme for analysis.

Society of Cement Manufacturers' Salt water Committee.

2 gr. cement (or mortar, that has originally contained 2 gr. cement, for example 6 gr. for the mortar admixture 1 : 2) to be treated with diluted hydrochloric acid, vaporised and heated to 120 degrees C. on a sand bath; a few drops of hydrochloric acid is added and it is allowed to stand for half an hour; it is then treated with boiling water and filtered into a half liter bottle. The precipitate is boiled three times with carbonate of soda, filtered, washed, heated to red heat and weighed:

insoluble matter.

The solution in carbonate of soda is neutralized with hydrochloric acid, vaporised and heated to 120 degrees C.; after addition of a few drops of concentrated hydrochloric acid it is treated with boiling water, filtered, heated to red heat and weighed:

soluble SiO_2.

One half of the half liter bottle is, in boiling condition, precipitated with baryum chloride, filtered, heated and weighed; from this is calculated:

SO_3.

The other half is, in boiling condition, precipitated with ammonia, the surplus of ammonia is evaporated, it is then filtered, disolved in hydrochloric acid, again precipitated with ammonia, surplus of ammonia evaporated, filtered, heated and weighed:

R_2O_3.

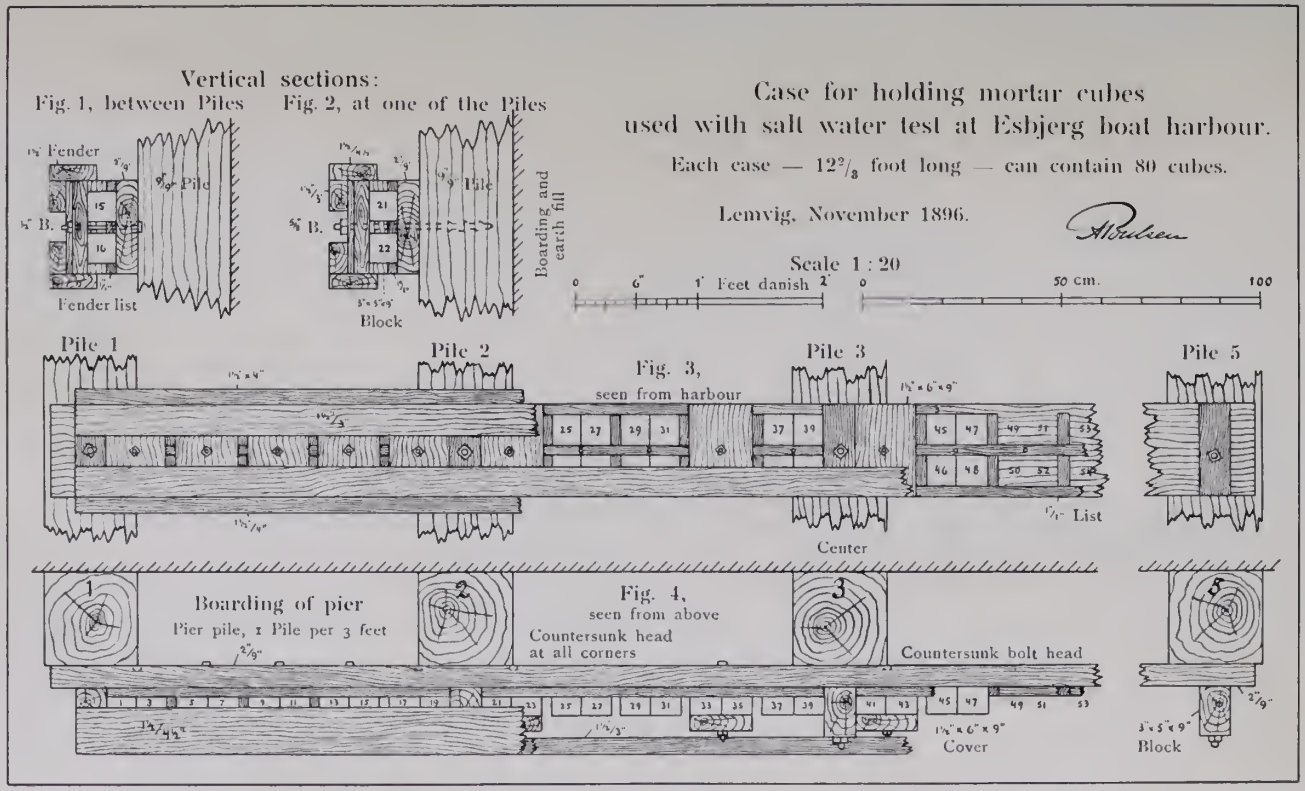
The filtrate from R_2O_3 is, boiling, precipitated with amonium-oxalate, filtered, dissolved in hydrochloric acid, precipitated, boiling, with ammonia, filtered, heated and weighed:

CaO.

The filtrate from CaO is evaporated and heated a little, dissolved in a few drops of hydrocloric acid; ammonia is added and it is filtered. To 50 cm^3 of the filtrate is added sodium phosphate and 50 cm^3 of ammonia, it is left for 24 hours, filtered, washed with alcohol and ammonia-water, heated, weighed, herefrom is calculated:

MgO.

Loss from ignition is determined for 1 gr. cement or a corresponding quantity of mortar.


Vertical sections:
Fig. 1, between Piles
Fig. 2, at one of the Piles
Fender
Pile
Fender list
Block
Boarding and earth fill
Case for holding mortar cubes
used with salt water test at Esbjerg boat harbour.
Each case — 12 2/3 foot long — can contain 80 cubes.
Lemvig, November 1896.
Scale 1 : 20
Feet danish
50 cm.
Pile 1
Pile 2
Pile 3
Pile 5
Fig. 3,
seen from harbour
List
Center
Boarding of pier
Pier pile, 1 Pile per 3 feet
Fig. 4,
seen from above
Countersunk head
at all corners
Countersunk bolt head
Cover
Block

Appendix 8.

Description to sketch

dated November 1896.

Case for holding the mortar cubes used for the sea water trials in Esbjerg boat harbour.

Place for the arrangement of a case — as shown in the sketch, $12^2/_3$ foot long and having place for up to 80 test cubes — was found under the steps leading down to the harbour for fishing boats at Esbjerg harbour. These cases are made as follows:

On a $2'' \times 9''$ plank — $12^2/_3$ foot long — are fastened five blocks $3'' \times 5'' \times 9''$, having the same distance apart as the pier piles, viz. 3 feet. Through each of these blocks as well as through the plank, a sufficiently large hole is bored, so that a $^5/_8''$ ragbolt can be hammered into the pier pile. In order to facilitate the removal of the case the heads of the ragbolts are screw-cut and not wrought on.

Wooden lists $1'' \times 1''$ are nailed to the plank betweeen the blocks so as to form divisions, in which the test cubes (about 7 cm. side line) can be placed in pairs, beside each other: over each four cubes is placed a $1\frac{1}{2}''$ cover, which is fastened down by a $\frac{1}{2}''$ screwbolt through the plank. Besides this bolt the covers are nailed down with a couple of nails from above and below through the fenderlists, which are also nailed to the sides of the case (blocks), viz: 1 list $1\frac{1}{2}'' \times 3''$ and 1 list $1\frac{1}{2}'' \times 4\frac{1}{2}''$ on each side. The fender lists are nailed to each other along the edge.

When the cubes are placed in the divisions, a 7 cm. slice, cut from good ragboard (not pasteboard) eventually with upturned edges, is placed below them, so that the cubes shall fit

tightly between the lists. Similarly a slice is placed between the cubes and the cover (about 15 cm.× 18 cm.).

When placing the cubes in the case, care must be taken, that a certain surface is turned towards the cover — as specified by the State laboratory for testing materials.

All bolts and nails to be galvanized. At Esbjerg the cases for the later years cubes should be made of oak, as a few Toredo and other crustacea are found there. In Vardø it will, for the same reason, be necessary, to a certain extent, to make the cases of Green-heart, but at Degerhamn, deal can be used for all the cases.

1 Danish foot = 12″= 31,4 cm.

Appendix 9.

Arrangement of the mortar cube cases.

Tests in Esbjerg (South side of boat harbour).

a. *Tests cases placed 0.7 m. above daily low water (mean tide).*

Testing Laboratorys No. . . .	16	14	12	8	10	18	20	22	45
Class of wood in cases	deal	deal	deal	deal	oak	oak	oak	oak	oak
Kept in sea water, years . . .	1/4	1/2	1	2	4	6	10	15	20
Placed 1897, date	24/2	25/2	27/2	1/3	1/3	2/3	2/3	5/3	5/5
Taken up: (1897—1917)	May 97	Aug. 97	Febr. 98	March 99	Aug. 01	Sept. 03	July 07	Febr. 12	Apr. 17

b. *Tests cases placed 0.5 m. under daily low water.*

Testing Laboratorys No. . . .	17	15	13	9	11	19	21	23	46
Class of wood in cases	deal	deal	deal	deal	oak	oak	oak	oak	oak
Kept in sea water, years . . .	1/4	1/2	1	2	4	6	10	15	20
Placed 1897, date	24/2	25/2	27/2	1/5	1/3	2/3	2/3	5/3	5/5
Taken up: (1897-1917)	May 97	Aug. 97	Febr. 98	March 99	Aug. 01	Sept. 03	July 07	Febr. 12	Apr. 17

Tests at Vardø.

c. *Tests cases placed 2 m. over daily low water (mean tide).*

Testing Laboratorys No. . . .	24	25	29	30	32	35	43	44	42
Class of wood in cases	deal	deal	deal	deal	deal	deal	Green-heart	Green-heart	Green-heart
Kept in sea water, years . . .	1/4	1/2	1	2	4	6	10	15	20
Placed 1897, date	5/4	5/4	6/4	6/4	7/4	19/4	25/5	25/5	25/5
Taken up: (1897—1917)	June 97	Oct. 97	Apr. 98	Apr. 99	Apr. 01	Aug. 03	June 07	Apr. 12	Apr. 17

d. *Tests cases placed under lowest water mark.*

Testing Laboratorys No.	40	41	31	34	37	38	26	27	39
Class of wood in cases	Green-heart	Green-heart	oak	oak	oak	oak	oak	oak	Green-heart
Kept in sea water, years	1/4	1/2	1	2	4	6	10	15	20
Placed 1897, date	6/4	6/4	7/4	19/4	22/5	22/5	22/5	22/5	22/5
Taken up: 1897—1917	reserve		Apr. 98	Apr. 99	May 01	Aug. 03	June 07	Apr. 12	Apr. 17

Tests at Degerhamn (»Nordre Bro's« southern quay).

e. *Tests cases placed under lowest water mark.*

Testing Laboratorys No.	2	3	4	5	6	7	28	33	36
Class of wood in cases	deal	deal	deal	deal	deal	deal	deal	deal	deal
Kept in sea water, years	1/4	1/2	1	2	4	6	10	15	20
Placed 1898, date	28/2	28/2	8/3	8/3	16/3	16/3	19/3	19/3	23/3
Taken up: 1898—1918	Apr. 98	July 98	Febr. 99	Febr. 00	Febr. 02	Nov. 03	Sept. 08	Febr. 13	Febr. 18

Appendix 10.

Concrete test blocks in groin No. 59 at Thyborön.

The quality of the mortar is marked with numbers 10—0, according to judgement. The No. 0 indicates that the block is quite destroyed.

Prog. Nr.	Brand of cement	Mixture	Date moulded	Date placed	Quality	Appearance	Notes on condition 1909
1	Christiania	1 : 1	$^{17}/_{11}$ 96	$/_{8}$ 97	10	good	
2	—	1 : 2	$^{17}/_{11}$ 96	$/_{8}$ 97	10	good	Begun to sweat.
3	—	1 : 3	$^{17}/_{11}$ 96	$/_{8}$ 97	0		Destroyed in Dec. 1905.
4	Lomma	1 : 1	$^{18}/_{11}$ 96	$/_{8}$ 97		good	At present not in its place.
5	—	1 : 2	$^{18}/_{11}$ 96	$/_{8}$ 97	0		Destroyed Dec. 1905.
6	—	1 : 3	$^{18}/_{11}$ 96	$/_{8}$ 97	0		Destroyed June 1905.
7	Aalborg	1 : 1	$^{19}/_{11}$ 96	$/_{8}$ 97	9	good	
8	—	1 : 2	$^{19}/_{11}$ 96	$/_{8}$ 97	8	good	
9	—	1 : 3	$^{19}/_{11}$ 96	$/_{8}$ 97	1		One half part destroyed.
10	Nine Elms	1 : 1	$^{13}/_{11}$ 96	$/_{8}$ 97	9	good	Begun to crack.
11	—	1 : 2	$^{13}/_{11}$ 96	$/_{8}$ 97	10	good	
12	—	1 : 3	$^{16}/_{11}$ 96	$/_{8}$ 97	6		Perceptibly attacked 1901 — about $^{1}/_{8}$ is now destroyed.
13	Chaux du Teil	1	$^{20}/_{11}$ 96	$/_{8}$ 97			Signs of destruction 1901. Washed away Jan. 1901.
14	—	2	$^{21}/_{11}$ 96	$/_{8}$ 97	2		Perceptibly attacked 1901, partly destroyed now.
15	—	3	$^{21}/_{11}$ 96	$/_{8}$ 97			Signs of destruction in December 1899.

Concrete blocks with different sand (Aalborg cement).

Prog. Nr.	Sand admixture	Mixture	Date moulded	Date placed	Quality	Appearance	Notes on condition 1909
16	$^{6}/_{6}$ C	1 : 2	$^{5}/_{4}$ 97	$/_{8}$ 97	9	good	
17	$^{6}/_{6}$ M	1 : 2	$^{9}/_{4}$ 97	$/_{8}$ 97	9	good	
18	$^{6}/_{6}$ F	1 : 2	$^{5}/_{4}$ 97	$/_{8}$ 97	8	good	
(19)	$^{3}/_{6}$ C + $^{3}/_{6}$ M	1 : 2	$^{7}/_{4}$ 97	$/_{8}$ 97			Removed Jan. 1901. See No. 28.
20	$^{3}/_{6}$ C + $^{3}/_{6}$ F	1 : 2	$^{5}/_{4}$ 97	$/_{8}$ 97	10	good	
21	$^{3}/_{6}$ M + $^{3}/_{6}$ F	1 : 2	$^{8}/_{4}$ 97	$/_{8}$ 97	10	good	
22	$^{2}/_{6}$ C + $^{2}/_{6}$ M + $^{2}/_{6}$ F	1 : 2	$^{5}/_{4}$ 97	$/_{8}$ 97	10	good	
23	$^{1}/_{6}$ C + $^{1}/_{6}$ M + $^{4}/_{6}$ F	1 : 2	$^{7}/_{4}$ 97	$/_{8}$ 97	9	good	
24	$^{1}/_{6}$ C + $^{4}/_{6}$ M + $^{1}/_{6}$ F	1 : 2	$^{9}/_{4}$ 97	$/_{8}$ 97	8	good	
25	$^{4}/_{6}$ C + $^{1}/_{6}$ M + $^{1}/_{6}$ F	1 : 2	$^{7}/_{4}$ 97	$/_{8}$ 97	5		Sweating and small cracks.
26	$^{4}/_{6}$ C + $^{2}/_{6}$ F	1 : 2	$^{24}/_{4}$ 97	$/_{8}$ 97	6		Begun to be destroyed, sweatings.
27	$^{4}/_{6}$ M + $^{2}/_{6}$ F	1 : 2			7	good	
28	$^{3}/_{6}$ C + $^{3}/_{6}$ M	1 : 2	$^{7}/_{4}$ 97	$/_{10}$ 97	7	good	Replaced No. 19.
29	$^{6}/_{6}$ C	1 : 3	$^{9}/_{4}$ 97	$/_{8}$ 97	8	good	
30	$^{6}/_{6}$ M	1 : 3	$^{14}/_{4}$ 97	$/_{8}$ 97	8	good	
31	$^{6}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{8}$ 97	7	strongly granulated	
32	$^{3}/_{6}$ C + $^{3}/_{6}$ M	1 : 3	$^{9}/_{4}$ 97	$/_{8}$ 97	8	good	
33	$^{3}/_{6}$ C + $^{3}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{8}$ 97	6		Cracks and sweatings.
(34)	$^{3}/_{6}$ M + $^{3}/_{6}$ F	1 : 3	$^{13}/_{4}$ 97	$/_{8}$ 97			Washed away 1902. See No. 41.
(35)	$^{2}/_{6}$ C + $^{2}/_{6}$ M + $^{2}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{8}$ 97			Washed away Jan. 1901. See No. 42.
(36)	$^{1}/_{6}$ C + $^{1}/_{6}$ M + $^{4}/_{6}$ F	1 : 3	$^{13}/_{4}$ 97	$/_{8}$ 97			Washed away 1902. See No. 43.
37	$^{1}/_{6}$ C + $^{4}/_{6}$ M + $^{1}/_{6}$ F	1 : 3	$^{12}/_{4}$ 97	$/_{8}$ 97	9	good	
(38)	$^{4}/_{6}$ C + $^{1}/_{6}$ M + $^{1}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{8}$ 97			Washed away Jan. 1901. See No. 44.
(39)	$^{4}/_{6}$ C + $^{2}/_{6}$ F	1 : 3	$^{22}/_{4}$ 97	$/_{8}$ 97			Washed away Jan. 1901. See Nr. 45.
40	$^{4}/_{6}$ M + $^{2}/_{6}$ F	1 : 3	$^{22}/_{4}$ 97	$/_{8}$ 97	9	good	
41	$^{3}/_{6}$ M + $^{3}/_{6}$ F	1 : 3	$^{13}/_{4}$ 97	$/_{12}$ 02	9	good	Block for replacing No. 34.
42	$^{2}/_{6}$ C + $^{2}/_{6}$ M + $^{2}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{10}$ 01	10	good	— — » 35.
43	$^{1}/_{6}$ C + $^{1}/_{6}$ M + $^{4}/_{6}$ F	1 : 3	$^{13}/_{4}$ 97	$/_{12}$ 02	9	good	— — » 36.
44	$^{4}/_{6}$ C + $^{1}/_{6}$ M + $^{1}/_{6}$ F	1 : 3	$^{10}/_{4}$ 97	$/_{10}$ 01	9	good	— — » 38.
45	$^{4}/_{6}$ C + $^{2}/_{6}$ F	1 : 3	$^{22}/_{4}$ 97	$/_{10}$ 01	10	good	— — » 39.

Blocks of other brands of cement.

Prog. No.	Brand of cement	Mixture	Date moulded	Date placed	Quality	Appearance	Notes on condition 1909
46	Dania	1 : 1	$^{3}/_{4}$ 97	$/_{8}$ 97	10	good	
47	—	1 : 2	$^{3}/_{4}$ 97	$/_{8}$ 97	10	good	
48	—	1 : 3	$^{3}/_{4}$ 97	$/_{8}$ 97	9	slightly indented	
49	Cimbria	1 : 1	$^{21}/_{4}$ 97	$/_{8}$ 97	9	good	
50	—	1 : 2	$^{21}/_{4}$ 97	$/_{8}$ 97	7		Begun to crack.
51	—	1 : 3	$^{22}/_{4}$ 97	$/_{8}$ 97	2		Cracked right across.
52	Hellekis	1 : 1	$^{2}/_{4}$ 97	$/_{8}$ 97	10	good	
53	—	1 : 2	$^{2}/_{4}$ 97	$/_{8}$ 97	10	good	
54	—	1 : 3	$^{2}/_{4}$ 97	$/_{8}$ 97	0		Destroyed Dec. 1905.
55	Sand cement Aalborg	1	$^{12}/_{4}$ 97	$/_{8}$ 97	4	slightly indented	Begun to crack.
56	—	2	$^{12}/_{4}$ 97	$/_{8}$ 97	6	strongly indented	Perceptibly attacked in Dec. 1961. Block now cracked.
57	—	3	$^{12}/_{4}$ 97	$/_{8}$ 97	4	strongly indented	Perceptibly attacked Dec. 1901.
58	Aalborg + Trass	1	$^{21}/_{4}$ 97	$/_{8}$ 97	9	quite indented	
59	—	2	$^{13}/_{4}$ 97	$/_{8}$ 97	7	strongly indented	Perceptibly attacked Dec. 1901.
60	—	3	$^{21}/_{4}$ 97	$/_{8}$ 97			Washed away Jan. 1901.
61	Aalborg + infus. earth	1	$^{23}/_{4}$ 97	$/_{8}$ 97	8	strongly indented	
62	—	2	$^{22}/_{4}$ 97	$/_{8}$ 97	8	strongly indented	
63	—	3	$^{23}/_{4}$ 97	$/_{8}$ 97	6	strongly indented	
64	Sil. Lomma	1	$^{7}/_{11}$ 98	$/_{10}$ 00	9	good	See No. 85.
65	—	2	$^{7}/_{11}$ 98	$/_{10}$ 00			Washed away Jan. 1901. See No. 86.
66	—	3	$^{7}/_{11}$ 98	$/_{10}$ 00			Washed away Jan. 1901. See No. 87
67	Danmark	1 : 1	$^{17}/_{11}$ 98	$/_{10}$ 00	10	good	
68	—	1 : 2	$^{17}/_{11}$ 98	$/_{10}$ 00	8	good	
69	—	1 : 3	$^{17}/_{11}$ 98	$/_{10}$ 00	0		Destroyed Decr. 1905.
70	Slag cement	1 : 1	$^{26}/_{1}$ 00	$/_{10}$ 00	8	indented round edges	
71	—	1 : 2	$^{26}/_{1}$ 00	$/_{16}$ 00	2	rather indented	Cracked.
72	—	1 : 3	$^{26}/_{1}$ 00	$/_{10}$ 00	4	very indented	A layer of about 2 cm. fallen off.
73	Special brand Dania	1 : 1	$^{3}/_{9}$ 00	$/_{10}$ 01	10	good	
74	—	1 : 2	$^{3}/_{9}$ 00	$/_{10}$ 01	10	good	
75	—	1 : 3	$^{3}/_{9}$ 00	$/_{10}$ 01	9	good	

Prog. No.	Brand of cement	Mixture	Date moulded	Date placed	Quality	Appearance	Notes on condition 1909
76	Hemmoor	1 : 1	25/9 00	/10 01	8	good	
77	—	1 : 2	25/9 00	/10 01	8	good	
78	—	1 : 3	25/9 00	/10 01	8	good	
79	Sand cement (Lomma)	1	5/8 01	/10 01	8	good	
80	—	2	5/8 01	/10 01	7	slightly indented	
81	—	3	6/8 01	10 01	6	slightly indented	
82	Norden	1 : 1	17/8 01	/10 01	10	good	
83	—	1 : 2	17/8 01	/10 01	10	good	
84	—	1 : 3	17/8 01	/10 01	8	good	
85	Sil. Lomma	1	21/8 01	10 01	9	slightly indented	See No. 64.
86	—	2	21/8 01	/10 01	8	slightly indented	Replaced No. 65.
87	—	3	21/8 01	/10 01	6	slightly indented	Replaced No. 66.
88	Kinnipple	gew.	14/7 02	/12 02	8		The blocks are good, but have on account of moulding, a stony surface.
89	—	fein	4/8 02	/12 02	8		
90	—	gew.	4/8 02	/12 02	8		
91	Aalborg + Tras	1	12/9 02	/12 02	7	slightly indented	
92	—	2	12/9 02	/12 02	6	slightly indented	
93	—	3	12/9 02	/12 02	6	slightly indented	
94	Monier block	1 : 1	13/5 03	/3 05	10	good	
95	—	1 : 2	19/5 03	/3 05	10	good	
96	—	1 : 3	25/5 03	/3 05	10	good	
97	cement + Santorin	1	2/11 03	3 05	9	good	
98	—	2	2/11 03	/3 05	8	good	
99	—	2½	10/11 03	/3 05	7	indented	
100	—	3	2/11 03	3 05	8	slightly indented	
101	cement + Neap.Puzzol.	1	7/11 03	/3 05	10	good	
102	—	2	7/11 03	/3 05	9	good	
103	—	2½	10/11 03	/3 05	7	slightly indented	Begun to crack.
104	—	3	7/11 03	3 05	8	slightly indented	
105	lime + Santorin	1 : 3	19/11 03	3 05	4	strongly indented	

Prog. No.	Brand of cement	Mixture	Date		Quality	Appearance	Notes on condition 1909
			moulded	placed			
106	lime + Puzzolan	1 : 3	$^{19}/_{11}$ 03	$/_{3}$ 05	2	strongly indented	
107	gypsum free Aalborg	1 : 1	$^{20}/_{9}$ 04	$/_{3}$ 05	10	good	
108	—	1 : 2	$^{20}/_{9}$ 04	$/_{3}$ 05	10	good	
109	—	1 : 3	$^{20}/_{9}$ 04	$/_{3}$ 05	9	good	
110	cement + infus. earht	1	$^{14}{}_{7}$ 06	$/_{7}$ 07			
111	—	2	$^{19}/_{7}$ 06	$/_{7}$ 07			
112	—	$2^{1}{}_{3}$	$^{19}/_{7}$ 06	$/_{7}$ 07			
113	—	3	$^{19}/_{7}$ 06	$/_{7}$ 07			
114	cement + röm. Puzzol.	1	$^{14}/_{7}$ 06	$/_{7}$ 07			
115	—	2	$^{14}/_{7}$ 06	$/_{7}$ 07			
116	—	3	$^{14}/_{7}$ 06	$/_{7}$ 07			

Appendix 13.

Results of the investigations of the five brands of cement used for the mortar cubes, from the State Laboratory for testing Materials at Copenhagen.

			Christiania	Lomma	Aalborg	Nine Elms	Chaux du Teil
Setting test		% water	26½	26	27	23	47½
		setting time	9 hours	9½ hours	10½ hours	14 min.	25 hours
		rise of temperature	1,8 degr.	1,4 degr.	2,2 degr.	11,4 degr.	0 degrees
Residue on sieve with 900 meshes per cm. □			1,2 %	0,4 %	0,1 %	2,8 %	0,8 %
with 5000 meshes per cm. □			17,5 %	15,1 %	9,8 %	20,6 %	15,2 %
Weight per liter		loose	1298 gr.	1220 gr.	1314 gr.	1304 gr.	798 gr.
— —		shaken together	1809	1827	1946	1933	1253
Weight, not ignited			3,09	3,10	3,12	3,06	2,81
— ignited			3,18	3,19	3,19	3,20	3,27
loss from ignition			1,83 %	2,04 %	2,54 %	2,87 %	9,11 %
1 gr. reduces mgr. kalium permanganate			5,55	1,95	1,08	2,05	—
Normal test for volume consisteney			passed	passed	passed	passed	passed
1 cement, 3 Berlin normal sand		% water	9	9	9	9	11
	tensile strength	3 days	14,6 kg/cm²	14,8 kg/cm²	12,2 kg/cm²	6,0 kg/cm²	2,1 kg/cm²
		7 —	20,0	22,7	17,5	6,6	2,7
		28 —	26,3	25,0	22,1	11,4	9,2
	crushing strength	3 days	96,2 kg/cm²	105,8 kg/cm²	95,6 kg/cm²	48,0 kg/cm²	13,4 kg/cm²
		7 —	176,0	163,0	152,8	62,0	18,0
		28 —	263,0	226,0	221,8	94,1	35,5
Erdmengers test, 10 atmospheres, 6 hours	tensile		23,8 kg/cm²	22,7 kg/cm²	19,9 kg/cm²	boiled to pieces	15,7 kg/cm²
	crushing		286,8	251,0	246,2		106,6

At Aalborg Portland Cement Works, a series of tests has been executed that has given the following results:

Tensile tests in fresh water.

Cement	Proportion of mixture	7 days	28 days	90 days	180 days	1 year	2 years	4 years	6 years	10 years
Aalborg cement		33,0	35,9	45,9	47,9	51,0	58,4	56,5	55,5	64,5
Nine Elms.	1 : 1	20,8	21,8	31,6	—	42,0	43,5	45,5	43,0	57,6
Chaux du Teil		4,0	9,9	19,0	28,0	32,8	30,4	26,1	31,5	37,5
Aalborg cement		17,0	24,3	28,4	29,3	34,5	36,6	36,9	36,1	36,8
Nine Elms.	1 : 3	12,8	15,2	18,5	—	28,5	30,9	26,9	31,5	31,0
Chaux du Teil		3,2	6,6	16,1	21,9	26,1	25,1	22,7	24,6	29,0

Appendix 14. **Results in Kg/cm². of**

Test place	Age	Christiania cement with Bornholm normal sand			Lomma cement with Bornholm normal sand		
		1 : 1	1 : 2	1 : 3	1 : 1	1 : 2	1 : 3
State Laboratory	1 mth.	431	362	207	432	361	210
Degerhamn completely under water	1/4 year	583	573	288	555	555	266
	1/2 —	661	590	361	653	605	336
	1 —	622	561	353	563	533	333
	2 —	491	484	344	491	463	317
	4 —	582	520	307	583	528	276
	6 —	549[1]	535	340[1]	547	504	309
	10 —	516	561	312	560	495	301
Esbjerg completely under water	1/4 —	455	413	247	473	418	245
	1/2 —	507	481	301	546	486	274
	1 —	503	464	248	493	478	240
	2 —	380	381	247	433	422	259
	4 —	587	464	237	498	451	250
	6 —	468	486	266	388	476	247
	10 —	553	515	261	479	400	251
Esbjerg at mean tide mark	1/4 —	446	407	244	420	415	255
	1/2 —	452	485	283	544	489	281
	1 —	473	485	280	522	485	251
	2 —	450	340	237	424	392	244
	4 —	501	487	276	402	448	238
	6 —	485	420	290	380	463	219
	10 —	515	415	197	527	414	282
Vardö completely under water	1/4 —	—	—	—	—	—	—
	1/2 —	—	—	—	—	—	—
	1 —	483	415	245	468	434	221
	2 —	421	384	246	498	355	249
	4 —	404	350	232	430	384	220
	6 —	478	443	225	456	411	247
	10 —	605	525[7]	296	553[7]	374	261[7]
Vardö at mean tide mark	1/4 —	487	432	270	481	431	258
	1/2 —	639	506	281	589	470	281
	1 —	499	435	229	480	409	248
	2 —	501	386	231[2]	488	368	221[1]
	4 —	446	284	114[2]	362	284	230
	6 —	436	358[9]	— [10]	516	376	— [11]
	10 —	551[7]	— [13]	— [13]	— [13]	— [13]	— [13]

[1] 3 tests.
[2] 4 tests, slightly rounded at edges.
[3] 2 tests, the one slightly, the other very rounded at edges.
[4] no tests.
[5] 3 tests, somewhat rounded at edges.
[6] tests very rounded at edges.
[7] 3 tests, the fourth destroyed.

crushing of mortar cubes.

Aalborg cement with Bornholm normal sand			Nine Elms with Bornholm normal sand			Chaux du Teil with Bornholm normal sand			Aalborg cement with strand sand.		
1 : 1	1 : 2	1 : 3	1 : 1	1 : 2	1 : 3	1	2	3	1 : 1	1 : 2	1 : 3
379	322	202	194	169	93	70	52	21	374	253	179
534	541	326	421	326	187	175	120	41	537	497	220
649	575	369	447	361	225	240	213	97	582	466	273
542	508	349	448	332	214	234	217	98	560	468	273
463	470	301	452	356	202	231	233	75	465	348	274
536	497	276	481	385	228	241	221	96	549	413	270
546	476	328	464	371	225	292	241	67	530	382	270
590	543	332	440	425	205	204	205	46	514	412	250
477	410	246	290	230	129	113	102	33	402	322	205
465	467	273	353	253	146	169	186	57	530	362	222
479	455	272	366	297	170	194	229	70	523	376	232
443	413	259	261	237	146	205	191	59	436	321	197
447	389	258	375	305	178	241	194	64	464	300	220
483	448	280	398	303	207	208	181	56	532	326	196
565	436	320	412	347	193	226	206	54[7]	570	336	199
429	392	248	279	200	132	101	93	33	325	303	195
551	442	316	377	267	166	173	202	66	460	317	238
533	468	258	405	279	155	197	192	70	437	339	236
455	376	243	173	212	146	208	180	60	438	308	172
480	435	252	377	315	179	217	198	67	499	357	236
510	355	303	364	297	203	235	212	63	487	263	218
456	474	319	356	345	203	236	200[7]	50[7]	519	407	236
—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—
444	393	231	339	240	121	160	136	35	472	299	203
447	340	231	359	258	144	193	172	64	426	305	119
400	314	241	344	211	161	193	158	67	413[2]	257	200
412	384	214	304	239	141	201	187	66	431	277	172
556	434	228	439	272	153	225	204	62[7]	476[7]	315	217
432	391	243	283	215	129	107	87	28	386	259	165
519	436	273	329	276	142	161	93	48	457	272	210
437	416	258	374	251	136	150	117	57	448	296	212
479[2]	381	181[3]	374	255	— [4]	149[5]	105[6]	— [4]	487	305	200[1]
308	340	202	291	177	76[7]	152[8]	100[8]	— [13]	390	218	164
479	359 [9]	— [10]	345	287[7]	— [4]	— [11]	— [11]	— [13]	492	354	194 [9]
562 [12]	— [13]	— [13]	421 [9]	— [13]	— [13]	— [13]	— [13]	— [13]	533[7]	— [13]	— [13]

[8] 4 tests, all partly destroyed.
[9] 4 tests, of which 2 were so damaged that they could not be tested.
[10] 3 tests, the fourth destroyed, and the 3 so damaged that they could not be tested.
[11] 4 tests, but so damaged that they could not be tested.
[12] 1 test, the others destroyed.
[13] all the tests destroyed.

Appendix 16 a.

Analysis of crushed mortar cubes.

Tests from Esbjerg.

Calculated composition for 100 parts of lime.

Aalborg cement.

		Original analysis	With strand sand completely under water, after years					Normal sand, at mean tide mark, after years				
			1	2	4	6	10	1	2	4	6	10
Neat cement	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2.	35,2	36,2	35,3	35,7	35,7	36,2	35,1	35,6	36,5	35,6	36,1
	R_2O_3	12,7	12,2	12,6	15,1	12,5	12,6	12,6	13,3	13,1	12,2	12,6
	MgO	1,9	2,2	1,9	3,5	2,0	1,9	2,6	2,1	2,1	1,9	1,8
	SO_3.	3,1	3,2	3,1	2,6	3,4	3,3	3,4	3,2	2,7	3,3	3,3
	Cl.	0,0	1,9	1,1	2,5	2,8	3,4	0,8	1,1	1,7	3,5	4,3
1 : 1	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2.	35,2	38,4	34,1	35,0	35,1	36,4	33,8	35,3	34,9	35,7	35,9
	R_2O_3	12,7	12,3	12,6	12,8	12,7	13,0	12,7	13,4	12,7	12,8	12,7
	MgO	1,9	2,0	1,7	1,4	2,0	2,1	2,0	2,3	2,2	2,1	2,1
	SO_3.	3,1	3,4	3,3	2,9	3,3	3,0	3,2	3,5	3,1	3,1	3,4
	Cl.	0,0	2,5	2,4	4,0	3,7	4,4	1,5	3,0	4,0	4,3	4,1
1 : 2	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2.	35,2	35,4	33,7	35,9	34,7	36,4	34,1	36,7	36,1	36,4	36,7
	R_2O_3	12,7	12,2	12,7	13,4	13,7	13,6	13,1	13,1	13,3	12,7	12,8
	MgO	1,9	2,2	1,7	2,1	2,1	1,9	1,9	2,3	2,2	2,0	2,2
	SO_3.	3,1	3,4	3,2	3,1	3,4	3,5	4,3	3,7	3,0	3,1	3,5
	Cl.	0,0	3,6	2,8	4,6	5,2	5,9	1,9	4,3	5,3	5,7	5,5
1 : 3	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2.	35,2	35,2	36,3	35,8	37,5	39,1	34,3	35,4	36,0	38,1	36,2
	R_2O_3	12,7	12,8	14,4	13,6	14,0	14,5	13,3	13,3	13,6	13,8	13,6
	MgO	1,9	2,5	1,9	2,0	2,8	1,6	2,0	2,3	2,1	2,3	2,6
	SO_3.	3,1	3,4	4,3	3,4	3,9	3,8	3,4	3,6	3,3	4,0	3,4
	Cl.	0,0	3,6	4,4	5,4	5,5	6,6	3,5	4,7	5,9	6,1	6,2

Appendix 16 b.

Analysis of crushed mortar cubes.

Tests from Esbjerg.

Calculated composition for 100 parts of lime.

Chaux du Teil.

		Original analysis	Normal sand completely under water, after years					Normal sand at mean tide mark, after years				
			1	2	4	6	10	1	2	4	6	10
Neat cement	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2	34,1	33,3	33,4	33,7	34,4	35,4	33,2	33,3	34,1	34,8	36,8
	R_2O_3	2,6	2,9	2,7	2,6	2,5	2,5	3,1	2,6	2,5	2,4	2,9
	MgO	1,2	1,8	2,2	1,8	1,8	2,0	1,6	1,9	2,0	1,8	1,6
	SO_3	0,6	0,9	1,0	0,9	1,8	0,9	0,7	0,9	0,9	0,9	0,7
	Cl	0,0	2,6	1,9	4,6	4,3	4,4	1,8	2,6	3,2	4,0	4,0
3:5	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2	34,1	31,7	30,5	34,8	34,7	37,6	35,1	39,2	31,8	37,2	37,6
	R_2O_3	2,6	3,4	4,2	3,2	2,9	3,6	3,6	3,8	3,3	3,1	3,2
	MgO	1,2	1,7	2,1	2,0	1,6	1,1	1,5	1,9	1,8	1,9	2,1
	SO_3	0,6	1,1	1,0	1,0	1,0	0,9	1,1	1,7	1,1	0,9	0,9
	Cl	0,0	2,2	2,4	4,5	4,4	5,7	2,8	3,0	3,5	4,0	5,1
2:5	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2	34,1	36,3	34,0	36,1	38,7	37,5	32,5	33,9	36,5	36,9	39,9
	R_2O_3	2,6	3,9	3,5	3,2	3,4	3,4	3,8	3,2	3,5	3,2	3,7
	MgO	1,2	2,0	2,3	2,1	2,0	1,9	2,0	2,2	2,0	1,8	2,1
	SO_3	0,6	1,3	1,1	2,8	1,2	0,9	1,2	1,0	1,2	0,9	1,8
	Cl	0,0	4,6	4,1	5,3	5,4	4,8	2,8	3,2	5,0	4,5	5,2
ca. 1:5 (23:120)	CaO	100	100	100	100	100	100	100	100	100	100	100
	solbl. SiO_2	34,1	35,5	38,4	41,0	54,1	60,6	37,5	39,7	40,2	44,5	54,7
	R_2O_3	2,6	4,4	4,6	4,3	6,0	6,4	4,9	4,7	4,6	4,7	5,2
	MgO	1,2	2,6	2,6	4,0	11,0	3,5	1,9	6,8	2,7	2,5	3,0
	SO_3	0,6	1,4	3,0	2,5	5,0	5,5	3,4	4,2	2,2	2,6	4,1
	Cl	0,0	1,3	1,5	3,0	3,1	6,7	1,7	4,3	3,8	3,7	2,9

Appendix 16 c.

Analysis of crushed mortar cubes.

Tests from Esbjerg.

Calculated composition for 100 parts of lime.

			Original analysis	Normal sand, at mean tide mark, after years					
				1/4	1	2	4	6	10
Chaux du Teil 2 : 5	From the center of the cube	CaO	100	100	100	100	100	100	100
		sollbl. SiO_2	34,1	34,6	34,6	33,9	34,2	35,1	35,2
		R_2O_3	2,6	3,3	3,7	3,3	3,4	3,3	3,2
		MgO	1,2	1,7	1,4	2,9	1,9	1,5	1,9
		SO_3	0,6	0,5	0,7	0,8	0,8	0,9	1,1
		Cl	0,0	2,0	2,8	2,9	4,1	3,9	4,5
	outer surface (to a depth of 1 cm.)	CaO	100	100	100	100	100	100	100
		sollbl. SiO_2	34,1	30,5	36,5	32,8	46,3	40,9	42,3
		R_2O_3	2,6	3,3	3,6	3,9	4,5	3,7	3,7
		MgO	1,2	2,3	0,9	2,3	3,8	2,1	2,3
		SO_3	0,6	1,2	1,3	1,2	1,9	1,8	1,7
		Cl	0,0	1,5	2,7	3,6	5,8	3,9	5,9
Nine Elms 1 : 2	From the center af the cube	CaO	100	100	100	100	100	100	100
		sollbl. SiO_2	38,2	37,3	36,2	36,7	37,7	38,2	37,8
		R_2O_3	18,7	19,1	19,3	19,2	19,4	19,1	19,3
		MgO	1,5	1,8	1,9	1,9	1,9	1,9	1,4
		SO_3	2,3	3,2	3,0	2,6	2,5	1,9	2,7
		Cl	0,0	—	1,3	2,6	4,1	4,8	4,3
	outer surface (to a depth of 1 cm.)	CaO	100	100	100	100	100	100	100
		sollbl. SiO_2	38,2	37,7	36,1	37,6	39,8	38,7	40,2
		R_2O_3	18,7	19,4	19,1	19,6	20,5	19,4	20,2
		MgO	1,5	1,7	1,6	3,1	4,2	2,3	1,8
		SO_3	2,3	3,0	2,6	3,1	4,1	3,6	3,5
		Cl	0,0	—	1,9	3,4	4,6	5,7	5,6

Tests from Vardø.

Complete analysis.

Chaux du Teil, ca. 1 : 5.

	Original analysis	Mean tide mark 4 years
insolbl. SiO_2	0,68	76,87
sollbl. SiO_2	22,52	3,73
R_2O_3	1,71	0,40
CaO	66,03	3,80
MgO	0,83	3,48
SO_3	0,39	1,66
Cl	0,00	0,10
loss by ignition	7,64	9,81
total	99,80	99,85

Calculated composition for 100 parts of lime.

	Original analysis	Mean tide mark 4 years
CaO	100	100
sollbl. SiO_2	34,1	97,9
R_2O_3	2,6	10,6
MgO	1,2	91,5
SO_3	0,6	43,7
Cl	0,0	2,7

Appendix 18.

Results in kg/cm.^{2} of the investigations of the State Laboratory for testing materials in Copenhagen, for some of the brands of cement used in the concrete blocks at groin no. 59, with the mixture of 1 measure cement + 3 measures normal sand.

			Danmark	Slagcement	Sil-Lomma	Norden	Aalborg sand test block 1901	»Lomma« 1901 sand cement
Setting test		% water	27½	35	32,5	28	26,5	24,0
		setting time	3½ h.	2½ h.	11½ h.	8½ h.	7½ h.	2½ h.
		rise of temperature	3,1dgr.	2,0dgr.	1,5dgr.	1,3dgr.	2,3dgr.	5,7dgr.
Residue on sieve with		900 meshes pr. cm□	1,2%	1,1%	0,5%	0,2%	0,0%	0,4%
		2500 — » »	10,5%	4,3%	5,9%	2,2%	1,8%	10,4%
		5000 — » »	21,5%	9,2%	14,7%	6,8%	5,4%	21,6%
Normal test for constancy of volume			passed	passed	passed	passed	passed	passed
1 cement and 3 Berlin normal sand		% water	9.0	10,0	9,5	9,0	9,0	9,0
	tensile	3 days	10,9	10,7	8,0	14.3	19,3	9,0
		7 »	20,7	14.8	14,6	17,2	20,4	11,7
		28 »	25,2	20,9	25,8	21,5	25,4	17,3
		3 months	28,2	25,5		29,9	27,7	22,2
	crushing	3 days	106,6	62,2	76,0	99,8	150,2	63,2
		7 »	156,0	97,6	140,8	195,6	196,8	90,8
		28 »	218,4	144,0	289,7	334,8	265,9	125,9
		3 months	272,6	172,4	311,0	333,5	301,6	153,6
Erdmenger's test after 3 days 10 atmospheres for 6 hours		tensile	22,5	13,3	27,9	24,9	27,8	16,9
		crushing	315,4	89,4	327,6	285,2	359,8	271,6

Appendix 20.

Crushing tests with concrete cubes.

Mark of the cube	Moulded	Date of test	Crushing load in kg cm²	Notes
Machine mixed 1 : 2½ : 5½	July 1902	Sept. 1902	139,7	
Hand mixed 1 : 2½ : 5½	July 1902	Sept. 1902	94,3	
Machine mixed 1 : 2½ : 5½	Sept. 1902	Novb. 1902	97,1	
Hand mixed 1 : 2½ : 5½	Sept. 1902	Novb. 1902	75,4	
Ordinary cement	23/7 04	22/9 04	143,3	average of 5 tests.
Gypsum free cement	25/7 04	22/9 04	112,6	— » 5 —
C + S 1 : 1	11/12 03	28/10 04	151	C = Cement.
C + S 1 : 2	11/12 03	28/10 04	75	S = Santorin.
C + S 1 : 2½	11/12 03	28/10 04	53	P = Neap. Puzzolan.
C + S 1 : 3	11/12 03	28/10 04	38	L = lime.
C + P 1 : 1	28/11 03	28/10 04	120	
C + P 1 : 2	28/11 03	28/10 04	74	
C + P 1 : 2½	11/12 03	28/10 04	48	
C + P 1 : 3	28/11 03	28/10 04	31	
L + S 1 : 3	30/1 04	28/10 04	15	
L + P 1 : 3	30/1 04	28/10 04	6	Load so small that it could not be determined with exactness.
Gypsum free »Norden« machine mixed	19/7 05	23/8 05	153	average of 5 tests.
C + PR 1 : 1	14/7 06	7/12 06	167	C = cement.
C + PR 1 : 2	14/7 06	6/12 06	75	PR = Rom. Puzzolan.
C + PR 1 : 3	14/7 06	0/12 06	37	
C + MLA	14/7 06	7/12 06	110	MLA = infus. earth. Litra A.
C + MLB	19/7 06	0/12 06	110	MLB = — — B.
C + MLC	19/7 06	7/12 06	87	MLC = — — C.
C + MLD	19/7 06	6/12 06	95	MLD = — — D.
No. 1. 1 : 4 : 8	7/10 07	20/1 08	58	
No. 2. 1 : 7	9/10 07	20/1 08	53	used locomotive ash as shingles.
No. 3. 1 : 2 : 4	12/10 07	20/1 08	73	

Appendix 21.

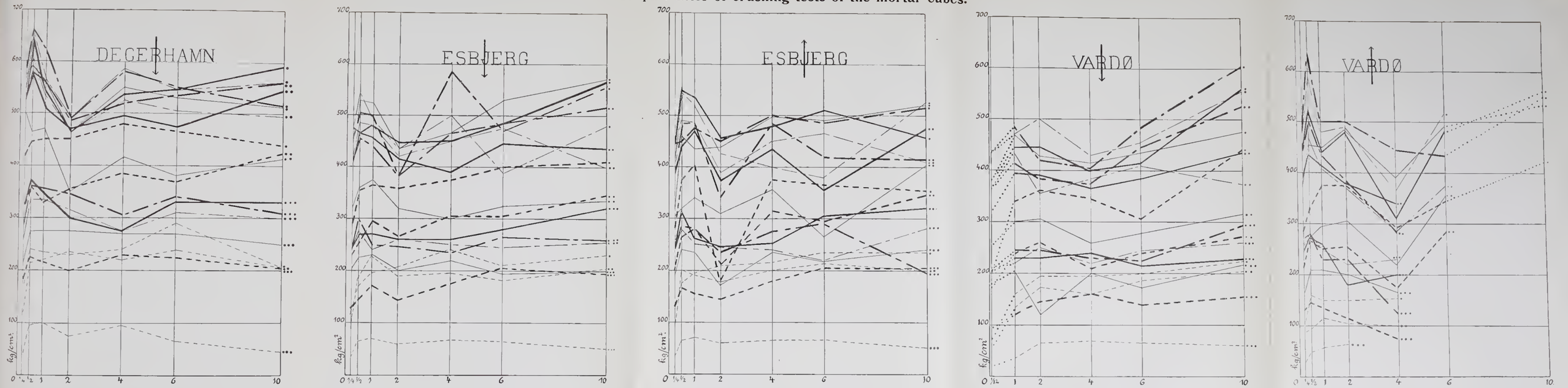
Analysis of concrete blocks, year 1900.

The samples are taken from those blocks which showed signs of destruction, and the numbers correspond to those in appendix 10.

	Chaux du Teil			Nine Elms	Sand cement		Aalborg cement with infus. earth			Aalborg cement with Tras	
Prog. No. . . .	13	14	15	12	56	57	61	62	63	59	60
Calculated original composition of dry mixtures.											
CaO	25,06	15,46	11,79	14,66	9,29	6,86	17,44	10,71	7,73	9,09	6,76
MgO	0,31	0,19	0,14	0,22	0,18	0,13	0,33	0,21	0,15	0,45	0,34
SO_3	0,15	0,09	0,07	0,34	0,29	0,21	0,54	0,32	0,24	0,29	0,22
Analysis of samples from year 1900.											
CaO	20,13	12,92	9,81	13,00	10,83	7,44	15,00	8,83	5,56	7,42	6,81
MgO	0,72	0,42	0,32	0,81	0,69	0,50	0,68	0,78	1,85	1,02	0,77
SO_3	0,60	0,31	0,19	0,71	0,63	0,41	0,56	0,40	0,39	0,40	0,34
Cl	1,07	0,67	0,63	0,90	0,75	0,51	0,51	0,28	0,82	0,33	0,37
Calculated original composition for 100 parts of lime.											
CaO	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
MgO	1,2	1,2	1,2	1,5	1,9	1,9	1,9	1,9	1,9	5,0	5,0
SO_3	0,6	0,6	0,6	2,3	3,1	3,1	3,1	3,1	3,1	3,2	3,2
Cl	0	0	0	0	0	0	0	0	0	0	0
Calculated composition of samples from year 1900 for 100 parts of lime.											
CaO	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
MgO	3,6	3,3	3,3	6,2	6,4	6,7	4,5	8,8	33,3	13,7	11,3
SO_3	3,0	2,4	1,9	5,5	5,8	5,5	3,7	4,5	7,0	5,4	5,0
Cl	5,3	5,2	6,4	6,9	6,9	6,9	3,4	3,2	14,7	4,4	5,4

Appendix 15.

Graphic table of crushing tests of the mortar cubes.

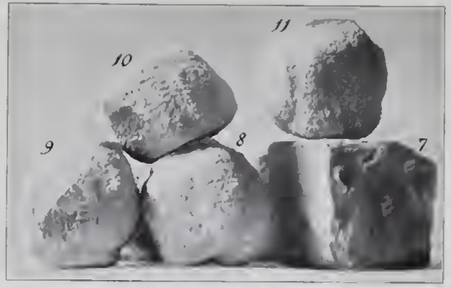


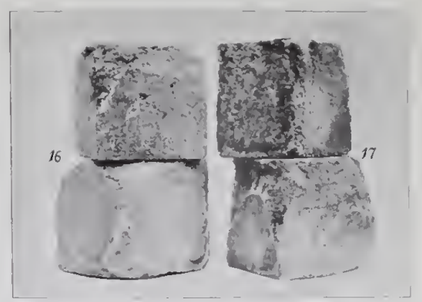
The diagram shows the strength in kilograms per cm², after a number of years, indicated by the abscisses, viz: 1 cm. = 50 kg cm², and 1 cm. = 1 year. The arrow through the name of the test place shows whether the tests have been kept under or above low-water.

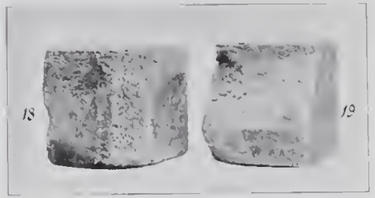
In each of the five diagrams will be found three curves of the same class, which denote the same brand of cement. The 1, 2 or 3 dots on the right side of the curve denote mortar 1 : 1, 1 : 2 and 1 : 3.

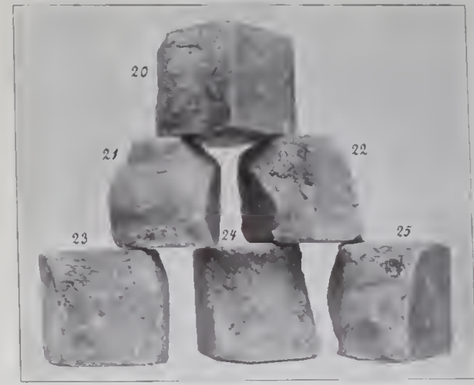
——— Aalborg.
Aalborg with strand sand.
——— — Christiania.
Lomma.
— — — Nine Elms.
Chaux du Teil.

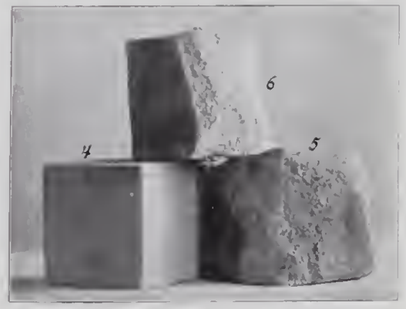
Tests from Vardö.

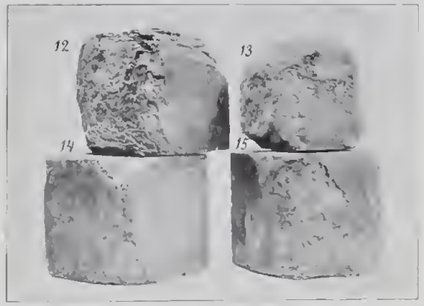


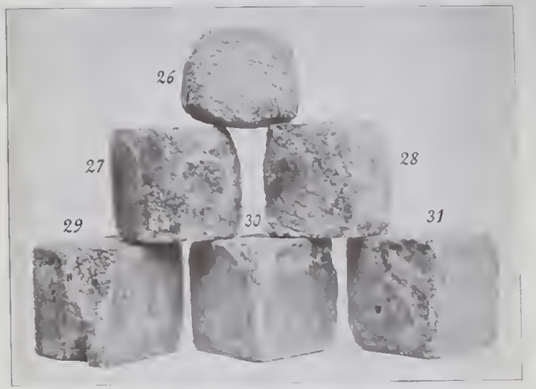












6 years at mean tide mark.

No. 1	Newly made test block.	No. 7.	Neat Chaux du Teil
- 2	Christiania 1 3.	- 8	Chaux du Teil 1 1 and 1 2
- 3	1 3	- 9	
- 4	Newly made test block.	- 10.	
- 5	Lomma 1 3	- 11	
- 6	1 3		

10 years at mean tide mark.

No. 12	Neat Chaux du Teil	No. 22	Aalborg + strand sand 1 3
- 13.	Neat Lomma	- 23.	1 2
- 14	Neat Christiania	- 24	1 2
- 15.	Neat Aalborg	- 25	1 2
- 16	Christiania 1 1	- 26	Aalborg + normal sand 1 3
- 17	Lomma 1 1	- 27	1 2
- 18	Nine Elms 1 2	- 28	1 2
- 19	1 2	- 29	1 1
- 20.	Aalborg + strand sand 1 1	- 30	1 1
- 21	1 3	- 31	1 1

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